ENHANCEMENT OF ECO-EFFICIENCY THROUGH LIFE CYCLE ASSESSMENT IN NATURAL RUBBER LATEX CONCENTRATE PROCESSING

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FACULTY OF ENGINEERING
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ABSTRACT

The three countries in South East Asia, namely Indonesia, Thailand and Malaysia are the world's largest produces of natural rubber in the world with a combined production capacity of 6.5 Mt annually. Field latex which normally consists of 20% dry rubber content (DRC) needs to be further concentrated to dry rubber content of 60% before it can be used for downstream products. The present practice in latex concentrate factories uses large volume of water and energy needs to be more efficient in their materials and energy usage and leads to environmental problems. The rubber industry needs to improve its competitiveness not only to increase profits but to ensure sustainability. Life Cycle Assessment (LCA) and Eco-Efficiency are used as the combined approach in this research to attain that objective.

The study was conducted on two selected natural rubber latex concentrate processing plants in North Sumatera. The main objectives of the study are to conduct life cycle inventory for natural rubber latex concentrate, analyze the environment impact from the life cycle processing activities, implement opportunities towards environmental improvements through LCA and also to suggest improvements of the impacts from the current practices of natural rubber latex concentrate processing towards eco-efficiency of the selected premises.

Two factories, A and B which produce latex concentrate as the main product and block skim rubber as by-product were chosen. Both factories use centrifugation as a concentration process. This study is a gate to gate study where data inventory starts from acceptance of latex in the plant until production of concentrated latex and block skim rubber. To determine the amount of impact that arise in this process, LCIA was

used using Eco-Indicator 99. The functional unit of the study is to process of 1,000 kg concentrated latex and 1,000 kg block skim rubber. Furthermore, the most influential impact was used to measure the eco-efficiency.

Based on the results obtained, Factory A contributed higher environmental impact than Factory B for both latex concentrate and block skim rubber processing. Damage to resources is very high, dominantly contributed from fossil fuel. Ammonia gives the highest impact in latex concentrate processing by 92.7% for Factory A with total impact of 30.998 Pt while in Factory B ammonia gives 98.8% impact with total impact of 22.675 Pt. The highest impact in block skim rubber processing for Factory A is caused by formic acid (46.5%) and plastic (40.5%) with a total impact of 5.483 Pt, while for Factory B it is caused by plastic (64.5%), sulfuric acid (27.6%) with a total impact of 3.439 Pt.

Based on eco-efficiency indicator, waste intensity is almost the same for both factories in latex concentrate processing. Water intensity for Factory A for latex concentrate and block skim rubber processing is greater than Factory B. Therefore Factory B is found to be more eco-efficient in water consumption. As for energy intensity, Factory A has greater energy intensity compared to Factory B both in latex concentrate and block skim rubber processing. Factory A provided greater emissions compared to Factory B. This indicates that factory B is more eco-efficiency in energy consumption.

ABSTRAK

Indonesia kini mempunyai ladang getah terbesar di dunia dengan keluasan 3.4 juta hektar, diikuti oleh Thailand seluas 2.6 juta dan Malaysia, 1.02 juta hektar. Walau bagaimanapun, pengeluaran getah Indonesia berjumlah 2.4 juta tan manakala pengeluaran getah Thailand mencapai 3.1 juta tan dan pengeluaran getah Malaysia mencecah 951,000 tan. Eksport getah Indonesia pada tahun 2011 adalah di sekitar juta tan, dan selebihnya adalah penggunaan domestik. Kualiti getah ditentukan oleh mengekalkan tahap kebersihan yang tinggi adalah sangat penting untuk bersaing di pasaran dusia. Jadi sudah tiba masanya industri getah meningkatkan daya saing dalam usaha untuk meningkatkan keuntungan dan memastikan kemampanan.

Kajian ini dijalankan pada dua kilang yang memproses lateks peat getah alam di premis terpilih di Sumatera Utara. Matlamat utama kajian ini adalah untuk menjalankan kehidupan kitaran inventori untuk lateks pekat getah alam dari premis terpilih, menganalisis impak ke alam sekitar daripada aktiviti kehidupan kitaran pemprosesan melaksanakan peluang ke arah peningkatan alam sekitar melalui LCA, untuk mencadangkan penambahbaikan impak dari amalan semasa lateks peat getah alam pemprosesan ke arah eko-kecekapan premis yang dipilih.

Dua kilang, A dan B yang menghasilkan lateks pekat sebagai produk utama dan blok skim getah sebagai produk akhir telah terpilih. Kedua-dua kilang menggunakan sentrifugatsi sebagai proses pemisahan. Penyelidikan ini merupakan satu kajian pintu ke pintu di mana inventori data bermula dari penerimaan getah di kilang sehingga pengeluaran lateks pekat dan blok skim getah. Dalam pengeluaran blok skim getah, koagulum daripada pembekuan skim getah dan ketulan cawan digunakan sebagai bahan mentah. Selain peralatan utama di atas, terdapat beberapa peralatan tambahan dan bahan

kimia. Di samping itu terdapat juga variasi dalam jumlah dan jenis bahan kimia yang digunakan, yang boleh menyebabkan perbezaan dalam kualiti dan kuantiti produk. Pengumpulan data inventori terdiri daripada input dan output bahan, tenaga dan air. Data telah dikumpulkan tiga kali dari masing-masing kilang. Untuk menentukan jumlah impak yang timbul dalam proses ini, LCIA telah digunakan menggunakan eko-indikator 99. Tambahan pula, kesan yang paling berpengaruh digunakan untuk mengukur eko-efisiensi. Unit fungsional studi adalah untuk memproses 1,000 kg lateks pekat dan 1,000 kg blok skim getah.

Berdasarkan hasil yang diterima, Kilang A menyumbang impak alam sekitar yang lebih tinggi daripada Kilang B dalam pemprosesan lateks pekat dan blok skim pemprosesan getah. Kerusakan terhadap fosil adalah sangat tinggi, kebanyakan disumbang dari bahan api fosil. Ammonia memberikan impak tertinggi dalam pemprosesan lateks peat dengan 92.7% untuk Kilang A dengan jumlah impak 30,998 Pt dan Kilang 98.8% B dengan jumlah impak 22,675 Pt. Kesan impak tertinggi dalam blok skim pemprosesan getah Kilang A adalah disebabkan oleh asid formik 46.5% dan plastik 40.5% dengan jumlah impak 5,483 Pt, manakala Kilang B disebabkan oleh plastik 64,5%, asid sulfurik 27.6% dengan jumlah impak 3,439 Pt.

Eco- efisiensi diukur melalui pengiraan eko-efisiensi dan eko-efisiensi indikasi. Kategori impak dan penilaian kerusakan digunakan untuk mengira eko-efisiensi. Intensiti sisa, intensiti tenaga dan intensiti air digunakan untuk mengukur indikasi eko-efisiensi.

Untuk pengukuran eko- efisiensi, 8 kategori impak daripada 11 kategori impak telah dipilih sebagai impak paling berpengaruh yang menyebabkan kemusnahan alam sekitar dari pemprosesan lateks pekat dan blok skim pemprosesan getah. Didapati bahawa kerusakan terhadap sumber member eko- efisiensi terendah pemprosesan lateks getah asli peat untuk kedua-dua kilang diikuti dengan kesihatan manusia. Oleh itu terdapat keperluan untuk menguruskan sumber dan kesihatan manusia dalam usaha untuk meningkatkan eko- efisiensi.

Berdasarkan indikasi eko- efisiensi, intensitas air untuk Kilang A pada pemprosesan lateks pekat dan blok skim pemprosesan getah adalah lebih besar daripada Kilang B. Oleh itu Kilang B didapati lebih eko-efisiensi dalam penggunaan air.

Dalam kajian ini, terdapat beberapa cara untuk meningkatkan Eko- Efisiensi melalui pengurusan bahan, tenaga dan air yang telah disyorkan.

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
BAPEDAL	Badan Pengendalian Dampak Lingkungan (Environmental Impact Management Agency)
BAPPENAS	Badan Perencanaan Pembangunan Nasional (The National Development Planning Agency)
BSR	Block Skim Rubber
BOD	Biological Oxygen Demand
CML	Centre of Environmental Science of Leiden University
COD	Chemical Oxygen Demand
DAP	Diammonium hydrogen phosphate
DALY	Disability Adjusted Life Years
DIW	Department of Industrial Work
DRC	Dry Rubber Content
EMS	Environmental Management System
EQA	Environmental Quality Act,
GAPKINDO	Gabungan Pengusaha Karet Indonesia (Indonesia Rubber Producers Association)
HA	High-Ammonia
I-O	Input-Output
IRSG	International Rubber Study Group
ISO	International Organization for Standardization
JSDA	Jaringan Sumber Daya Air (Water Resource Network)
KEP-MEN LH	Keputusan Menteri Lingkungan Hidup (Regulation of the Ministry of Environment Republic of Indonesia)

LA	Low-Ammonia
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MST	Mechanical Stability Time
NOEC	No Observed Effect Concentration
NR	Natural Rubber
NRTEE	The National Round Table on the Environment and the Economy
NRWS	Natural Rubber Waste Serum
OT	Onvangen Tank
PDF	Potentially Disappeared Fractions
PAF	Potentially Affected Fractionr
PE	Person Equivalent
PLN	Perusahaan Listrik Negara, Government Electricity Company
RBI	Rubber Board India
RPM	Revolution Per Minute
SNI	Standard Nasional Indonesia
SS	Suspended Solid
TSC	Total Solid Content
TMTD	Tetra Methyl Thiuram Disulfide
TZ	Tetra methyl thiuram disulfide-Zinc oxide
USEPA	United State Environment Protection Agency
VFA	Volatile Fatty Acid
ZnO	Zinc Oxide
WBCSD	World Business Council for Sustainable Development

CHAPTER 1

INTRODUCTION

1.1. Background

International forums have been raising much debate regarding the environmental issue such as global warming, ozone layer depletion, destruction of natural habitats and loss of biodiversity. Global warming and its several potential effects on the earth is a consequence of long-term accumulation of the so-called greenhouse gases mainly (CH_4, CO_2, N_2O) in the atmosphere (Khasreen, 2009). According to Asif, et al., (2007), human activities, such as deforestation, burning of fossil fuels and changes in land use, affect the emissions of these gases. They stated that in such a global environmental scenario, activities in all sectors should take sustainability consideration as their prime importance execution in order to secure the future for the next generation.

Concern for sustainability in the development and manufacture of new products is a strategy that is widely accepted in principle, although not yet widely practiced. The integration of environmental requirements throughout the entire lifetime of a product needs a new way of thinking and new decision tools to be applied (Kaebernick, 2003).

Sustainable management of materials and products involve continuous evaluation of ecological, economic, and social factors. A number of methods and tools are now available to support this strategy. One of the most common tool is life-cycle assessment (LCA). Even though LCA is a very influential instrument for assessing the impact of an activity on the environment, it still has some limitations or drawbacks. LCA has limitation related to methodological approach, time boundaries which will affect the quality of the data and availability and further will affect the results significantly (Benedetto, 2009). LCA often lacks a sustainability perspective and bring about difficult trade-offs between depth and details (Henrik, 2006). LCA only correlates between environmental and social factors and has limited inclusion of financial consideration. It is suggested that Eco-Efficiency can complement LCA for establishing a correlation between environmental and economic impacts thus leading the way towards the consideration for sustainability.

According to Verfaillie and Bidwell (2000) the concept of eco-efficiency itself was developed by the World Business Council for Sustainable Development (WBCSD) in 1992 and has been widely recognized by the business world. Eco-efficiency concept is suitable to the industrial world, because its practical approach makes it possible to balance environmental and economic benefits (Maxime, 2006). It shows how companies get the benefits with minimal impact to the environment. According to Braungart et.al., (2007) eco-efficiency basically means *doing more with less* – using environmental resources more efficiently; it improves environmental performance by reducing material, energy and other natural resources while minimizing cost and liabilities.

In fact according to Uson et al., (2011) wrote, from the eco-efficiency viewpoint in transport and mobility, eco-efficiency is more powerful than energy efficiency in achieving high levels of sustainability.

Today natural rubber (NR) is one of the natural resources that is used widely to make a variety of end products, such as tyres and medical related products. Natural rubber comes from the *Hevea brasiliensis* tree, which grows in tropical regions. The trees can reach 20-30 meters in height on rubber plantations and are able to start producing commercial quantities of latex at about 7 years of age, depending on climate and location. The average life span of a rubber tree is 32 years of which 25 years of productive phase (Roberson, 2012). The rubber tree originally grew in South America, then the seed was brought to Sri Lanka, Singapore, Malaysia and Indonesia, where the last two countries are currently the world's biggest natural rubber producer after Thailand (IRSG, 2012)

From the International Rubber Study Group report, global natural rubber production and consumption is still dominated by Asia (IRSG, 2012). Asia produces 10.3 Mt natural rubber or 93.6% of world's natural rubber production in 2011 and utilize 69.8% of 10.9 Mt world's consumption. This shows that Asia is the continent that most widely produces natural rubber and is also the highest consumer of natural rubber. The same report projected that the growth of natural rubber market would still increase up to the year 2025.

According to Amir (2012) from the Indonesian Rubber Producer Association (GAPKINDO), the installed capacity of rubber processing currently in Indonesia is about 4.4 Mt, but only consumes 2.9 Mt. Therefore, there is still unused capacity of about 1.5 Mt, because productivity is still low at only around 0.8 tons per hectare per year, while the productivity of rubber in Thailand is able to reach 1.5 tons per hectare per year. Rubber production in Indonesia in 2012 is expected to produce only 2.95 Mt which is the same as 2011, due to high rainfall and climate anomalies. Based on these conditions, the rubber production for domestic consumption is around 0.48-0.5 Mt, while for export it is approximately 2.4-2.5 Mt.

There are 218 rubber goods industries both small and big in Indonesia. Rubber goods industries in Indonesia are generally classified into several groups depending on the type of product, including tyre industries, engineering rubber good industries, latex good industries and general rubber goods industries (Rahman, 2009).

The growth of industry using rubber as raw material has seen progressive increment and this demand for rubber has been partly fulfilled through synthetic rubber (SR) production, in which synthetic rubber production is now higher than natural rubber as shown by statistics in Table 1.1 and Figure 1.1, Figure 1.2. Although natural rubber production is lower than the production and consumption of synthetic rubber but actually natural rubber can not be totally replaced by synthetic rubber. This is due to the fact that the natural rubber has better properties which includes: elastic or perfect resiliency, good plasticity, low heat build-up and groove cracking resistance. Synthetic rubber has advantages such as resistance to various chemicals and the price tends to remain stable, while natural rubber price always changes (Shifhit, 2012), (Swadaya, 2008).

Synthetic rubber is produced from petroleum which is a non-renewable resource. This means that natural rubber has good prospect for the future in term of its market demand. In 2008, the Asia/Pacific region consumed 56 percent of global rubber demand and China which is the largest market, is predicted to consume 30% of global rubber market in 2013 (Group, 2010). This rubber is mainly be used for motor vehicles, for the manufacture of tyres.

Table 1.1: World Rubber Production and Consumption

Year	**PRODUCTION (.000 tons)**			**CONSUMPTION (.000 tons)**		
	Natural	**Synthetic**	**Total**	**Natural**	**Synthetic**	**Total**

	Rubber	Rubber	Rubber	Rubber	Rubber	Rubber
1998	6,634	9,880	16,514	6,570	9,870	16,440
1999	6,577	10,390	16,967	6,650	10,280	16,930
2000	6,762	10,870	17,632	7,340	10,830	18,170
2001	7,332	10,483	17,815	7,333	10,253	17,586
2002	7,326	10,877	18,203	7,556	10,874	18,430
2003	8,006	11,338	19,344	7,937	11,350	19,287
2004	8,744	11,977	20,721	8,716	11,877	20,593
2005	8,907	12,073	20,980	9,205	11,889	21,094
2006	9,827	12,612	22,439	9,690	12,675	22,365
2007	9,890	13,347	23,237	10,178	13,296	23,474
2008	10,128	12,711	22,839	10,175	12,748	22,923
2009	9,690	12,385	22,075	9,330	12,248	21,578
2010	10,399	14,082	24,481	10,778	14,086	24,864
2011	10,974	15,115	26,089	10,924	14,926	25,850
2012	11,329	15,083	26,412	11,033	14,895	25,928

Source: *International Rubber Study Group, (2013)*

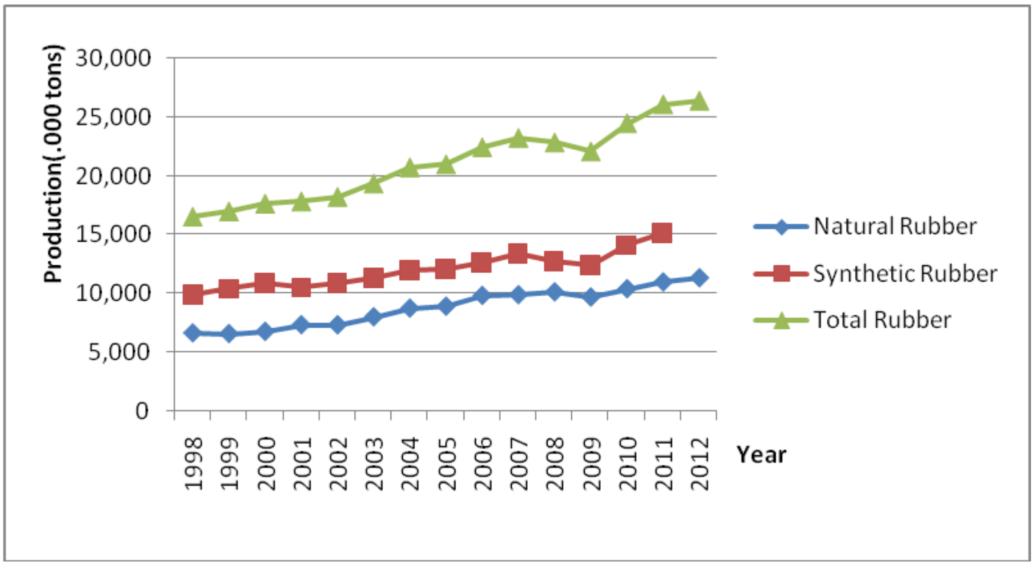

Figure 1.1: World Rubber Production

Source: *International Rubber Study Group, (2013)*

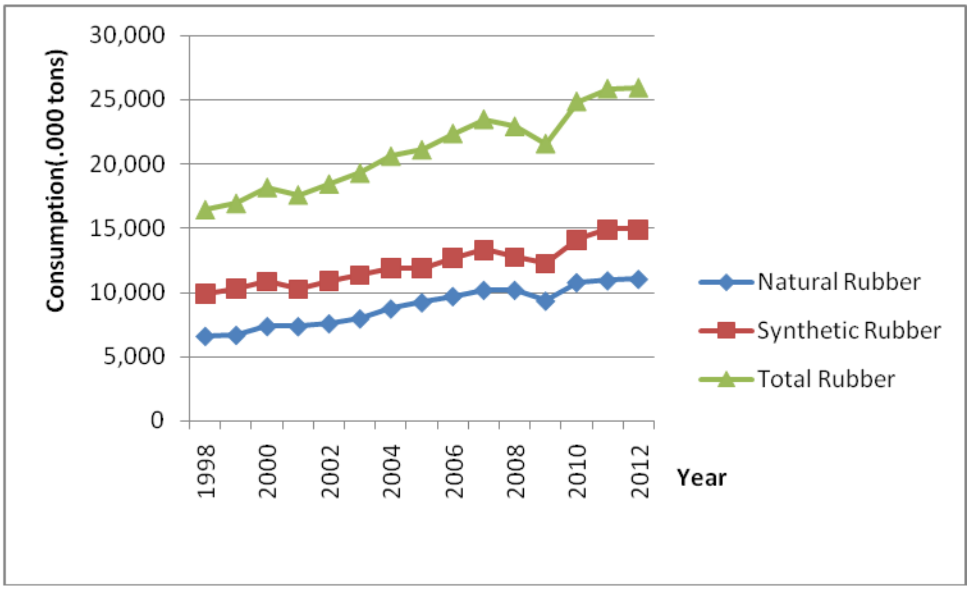

Figure 1.2: World Rubber Consumption

Source: *International Rubber Study Group, (2013)*

According to International Rubber Study Group (2013) global rubber consumption will grow at an average of 3.5 percent a year through 2018 as demand increases for replacement tires. Products from natural rubber latex concentrate processing produce many kinds of important rubber goods which provide big benefits to human beings.. However, environmental damages created from this processing could become a big issue. Handling natural rubber from upstream to downstream through several stages, start from plantation, intermediate product, and downstream products. This research reviews the life cycle of the intermediate product stage from field latex to produce latex concentrate and block skim rubber. Natural rubber latex concentrate processing uses large amount of chemicals and consumes large volumes of water and energy. The most common environmental issues are wastewater containing chemicals and odour. Therefore, waste abatement and management in natural rubber processing sector should be handled effectively and responsibly in order to reduce the damage to the environment.

1.2. Issues and Challenges in the Natural Rubber Latex Concentrate Processing Industry

The current technology to produce latex concentrate from natural rubber utilizes large quantities of water, energy and chemicals. Chemical which act as preservatives are added to prevent coagulation of rubber in latex and to precipitate the metals that can interfere with the centrifugation process in latex concentrate processing. Chemicals are also added in block skim rubber processing to form coagulum. Due to the volatile nature of the chemicals, this industry poses a bad risk to workers' health and the health of surrounding communities. Excessive or un-optimized use of natural resources and energy will definitely have negative impact on the environment. Additionally, the use of chemicals as preservatives to maintain grade or specification of rubber also lead to undesirable impact on the environment. The process of natural rubber latex concentrate requires a lot of water, so it will generate high volume of effluent containing un-coagulated rubber, proteins, carbohydrates and lipids among others. This effluent will cause water pollution that can damage health of surrounding communities.

Operating and maintenance procedures in many of the natural rubber latex concentrate processing are far from optimal. Losses in natural rubber latex concentrate processing would impact on the environment, which give rise to financial losses to the industry (Van, 2007). To overcome this, there should be an effort to reduce consumption of natural resources through measures such as focusing on technology so that natural resources processing will give maximum benefit to human life with minimum environmental damage (Nguyen, 2012).

Problems arising in natural rubber latex concentrate processing comes from wastewater which contains high amount of biological oxygen demand (BOD), chemical oxygen demand (COD), suspended solid (SS), ammonia, nitrogen, sulfate, acidity and odour. The characteristics of wastewater vary from each country due to differences in raw latex and applied technique of processing. Effective effluent treatment would minimize environmental pollution of rubber industry and bring it to become sustainable and environmental friendly (Mohammadi, 2010), (Nguyen, 2012) .

Based on the above information it shows that the process of natural rubber latex concentrate to produce latex concentrate and block skim rubber has a large negative impact on the environment. Then the question is how to achieve environmental improvements in parallel with economic benefits from the rubber industry.

There are opinions that link economic activities with environment and is known as eco-efficiency. World Council for Sustainable Development (2000) explained that eco-efficiency means producing goods and services using less energy and fewer raw materials, resulting in less waste, less pollution and less cost.

According to US President's Council on Sustainable Development, being eco-efficient means:

"maintaining economic growth while producing the absolute minimum of pollution."

According to van Berkel (2002), Eco-Efficiency is basically about making thoughtful use of materials, energy, water and other natural resources while conducting business. This is performed in order to improve the environmental performance of process products, while minimizing costs and liabilities.

In order to identify the impact of the natural rubber latex concentrate processing on the environment, assessment of its life cycle must be done. Currently, LCA in its present form can still be regarded as a rising environmental management tool with significant potential for supporting environmental decisions (UNEP, 2011). Many business associations and companies in industry already use the life-cycle approach in the framework of sustainability (EC, 2008). The European Commission (EC) concluded that LCA provides the best framework for assessing the potential environmental impacts. It provides a framework for analyzing and evaluating the environmental impacts of the life cycle products system. Life Cycle Assessment is used as a tool to support the eco-efficiency concept and will give a quantitative value of the impact caused by the processes through the Life Cycle Impact Assessment (LCIA). This potential of LCA as a tool can support the eco-efficiency approach (van Berkel, 2002). The case studies on the research in the West Australia grains sector, showed how LCA findings can be strategically linked to practical eco-efficiency targets at the sub-system or process level (van Berkel, 2007). In the case of natural rubber industry, Rattanapan (2012) developed the eco-efficiency indicator through material flow analysis for rubber glove product but yet to present the results in a quantitative basis.

1.3. Objectives of Study

The study is conducted on the selected premises of two natural rubber latex concentrate processing plants in North Sumatera.

The main objectives of the study are:

a). to conduct life cycle inventory study for natural rubber latex concentrate on the two selected premises

b). to analyze the environment impact from the life cycle processing activities and to evaluate and implement opportunities towards environmental improvements through LCA c). to assess level of eco-efficiency of the influence impacts to the environment from the current practices of natural rubber latex concentrate processing.

1.4. Scope of Study

The scope of study includes: the process, legality of requirement and evaluation procedure which are relevant to natural rubber latex concentrate processing.

1.4.1. The Process

The process includes the holistic life cycle of natural rubber latex concentrate processing, which includes latex concentrate as main product and block skim rubber (BSR) as by product in a factory. The study also involves the determination of chemical consumption, energy consumption and water consumption as inputs and air emission and wastewater as examples of the output.

1.4.2. Legal/Standards Requirement

Legal aspects of natural rubber latex concentrate in this study will be referred to:

- Regulation of the Ministry of Environment Republic of Indonesia: Kep-51/MEN LH/10/1995, with regards to Standard Requirement For Rubber Industry Wastewater (KLH, 1995a).
- Regulation of the Ministry of Environment Republic of Indonesia: Kep-13/MENLH/3/1995 on standards of quality for air emission from stationary source (KLH, 1995b).

  No: Kep -205/ Bapedal/07/1996 on the Chimney's Height, Environmental Impact Management Agency, (BAPEDAL, 1996).
- International Organization for Standardization, ISO 14040 series (ISO14040, 2006) and (ISO14044, 2006).

1.4.3. Evaluation Procedures

Evaluation of the existing condition has been simulated using Life Cycle Assessment software, SIMAPRO 7 by using methodology of Eco-Indicator 99, calculation of Eco-Efficiency and Eco-Efficiency Indicator. Calculation of Eco-Efficiency involves parameters that affect the Life Cycle Impact Assessment, that is an adverse impact on environment, while Eco-Efficiency Indicator is based on three parameters i.e., materials, energy and water.

1.5. Significance of Study

This study will benefit the natural rubber latex concentrate processing and related industry. The outcomes of this study are to suggest significant improvements and benefits for the company or industry and environment in the following manner:

- The company which use life cycle assessment as a tool for eco-efficiency strategies can reduce environmental burdens such as reduction in wastewater, energy usage, water usage, damage to resources and eco-system quality.
- The company which use eco-efficiency strategies can achieve reduced costs and increased profits as compared to similar firms that do not adopt eco-efficiency strategies. In addition, eco-efficiency can be used as a tool guide for approving capital investments, identifying and prioritize continuity of improvement, which needs to be done and provide information on strategic decisions to be made by company.
- Eco-efficiency principles will apply policies of the Government that encourage economic growth and reduction of resources utilization that will produce pollution. This policy can be done by avoidance or elimination of inappropriate subsidies

given as a cost to overcome negative impact to environment and social damage and prevent excessive use of resources.

1.6. Organization of Thesis

This dissertation has been divided into 5 chapters as follows:

Chapter One contains the introduction to the dissertation. It introduces background of the study, objectives of the study , scope of the study and contribution of the study.

Chapter Two presents the literature review. This chapter contains the theory of Environmental Management Systems. Concept of life cycle thinking is presented focusing on Life Cycle Assessment and the methodology following the ISO 14000 series. Theory of Eco-Efficiency is introduced, by Eco-Efficiency measurement and Eco-Efficiency Indicator. The detailed description of Life Cycle Impact Assessment and Eco-Efficiency is discussed. Description of natural rubber, properties and its processing are also described in this chapter.

Chapter Three explains the methodology that is used to conduct this research. The methodology consists of stages and detailed procedures that would be done to achieve the objectives mentioned in chapter one.

Chapter Four explains results and discussions. Data that have been collected were analyzed. Furthermore, the data are used to calculate the impact by using the LCA software and Eco-Efficiency measurement. The results were analyzed. Comparative analysis were conducted for factories that have been selected. Impact category that has been calculated is compared to direct measurements such as air emissions and wastewater. Measurements of air emissions and wastewater quality were also analyzed based on existing government regulations.

Chapter Five concludes the findings and recommendation from this research.

1.7. Publication

During this study, the author has published several papers in conference proceedings related to the topic of the research study. The list of the papers is presented in Appendix A.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

The latex of *Hevea brasiliensis* or natural rubber tree consists of 20%-35% rubber and the rest non-rubber material. Each pure rubber particle is surrounded by soapy-like substances which is made up of emulsion in aqueous (watery) phase. Carbohydrates, lipids, microorganisms, minerals, proteins and water are non-rubber matters in the aqueous phase and known as serum. Stability of the fresh latex is controlled by the existence of proteins and lipids (Ho, 1979).

Products of natural rubber can be classified into two phase categories, dry rubber such as crumb rubber and rubber sheet and liquid rubber which refers to latex concentrate. Higher rubber concentration known as latex concentrate is obtained after separation dry rubber content (DRC) by removing non-rubber materials. The rubber concentration is increased from 20-35% in field latex to 60%-65% DRC rubber concentration in latex concentrate and 3%-7% DRC concentration in skim latex and a little impurities.

There are several processes to produce latex concentrate: creaming, centrifugation, electro-decantation and evaporation.

Creaming: Cream agent such as ammonium alginate is mixed with field latex which will separate the latex rich rubber in the upper layer (concentrated latex) and low rubber (serum). A cream containing 60-68% rubber content is separated from the skimmed fraction after several weeks.

Centrifugation: The processing of field latex into latex concentrate by centrifugation will separate field latex into two layers. The upper layer contains concentrated latex with rubber content 60%-70% DRC and the lower layer contains skim latex containing rubber content 4%-7%.

Evaporation: The process is done by heating the latex at low pressure and high temperature so that water will evaporate. Alkali, (KOH) is used as preservative or stabilizer. Heating will evaporate the water resulting in 80% DRC in latex concentrate which contains total solid content (TSC) of more than 80%.

Electro-decantation: Electro-decantation uses electrode and semi- permeable membrane in its separation process. By electrolysis, negative charge in the field latex move towards a positive electrode and semi-permeable membrane will collect cream which is trapped in the surface of the membrane. The properties and composition of latex concentrate by electro-decantation process is similar to centrifugation process.

However two methods are commercially applied to produce latex concentrate from field latex, namely creaming and centrifugation (RBI, 2006).

According to White and De (2001), besides water and rubber as the primary constituents of field latex, it also consists of other components such as protein, resins, carbohydrate, minerals as shown in Table 2.1

Table 2.1: Field Latex Composition

No	Component	Percentage (%)
1.	Rubber	30-40
2.	Proteins	1-1.5
3.	Resins	1.5-3
4.	Carbohydtrates	0.8-1.0
5.	Minerals	0.7-0.9
6.	Water	55-60

Source: White and De. (2001)

Field latex is sterile in the vessel tree, but after contact with air, microbes in the air will grow exponentially with time. This is because field latex can be used as a medium that is suitable for microorganism growth. Microbes will decompose proteins and carbohydrates into short-chain acid molecules that are volatile (volatile fatty acids), and the latex will coagulate when isoelectric pH of 4 is reached (Anas, 2007). These microorganisms react mainly on the sugars and to a lesser extent the dissolved proteins in the serum, forming acids and other undesirable substances which will destabilize the rubber particles. To prevent premature coagulation and to preserve the latex from deterioration during storage some chemicals are added to inhibit bacterial growth. Therefore, some chemicals are necessary to add to avoid coagulation in the tapping cups and collecting buckets (Cecil, 2003).

According to John (2011), yeast in latex will produce alcohol by utilizing sugar. Normal hydration value of the protein layer surrounding the rubber particles will be reduced and destabilize the rubber particles because of the presence of alcohol as a dehydrating agent and coagulation takes place.

Destabilizing of natural rubber could be done physically and chemically. Physical destabilization could be caused by heating, freezing, mechanical agitation and removal of water (evaporation). Chemical destabilization occurs when acids and salts are added.

2.2. Natural Rubber Latex Concentrate Processing

Commercial latex concentrate, known either as high-ammonia (HA) or low-ammonia (LA) is generally produced by centrifugation. The concentration of ammonia per liter of latex in high ammonia and low ammonia latex concentrate are 6.0-7.0 g NH_3 and 4–5 g NH_3 respectively. High ammonia and low ammonia are usually used for the same functions such as to produce elastic thread, foam products, adhesives, dipped goods, household and industrial gloves, balloons and rubber bands. Low ammonia latex concentrate is more economic because it consumes lower acid and preservatives. Therefore the cost of production for LA is lower than HA latex concentrate.

Skim latex will coagulate with and without acid added and most of the non rubber particles are removed. Skim latex contains about 7% total solid content (TSC) and 5% dry rubber content (DRC). Dry rubber content is also addressed as DRC which means the weight of rubber in gram present in 100 gm of latex. According to Danwanichakul (2011), the total solid content (TSC) is measured by drying the latex sample to obtain the dried solid and it was found that for latex with DRC of 37.2%, TSC is 38.2%. Thus, the dissolved solid in the latex is about 1.0%.

Hevea tree produces a sap known as latex. To maintain latex in liquid phase, preservatives such as ammonia should be added into collection cups. Ammonia will prevent coagulation of latex. The solid phase can be obtained in a cup without adding the preservatives and is known as cup lump.

2.3. Latex Concentrate

According to Thaitex (2012) the parameters that determine quality of latex concentrate is as shown in Table 2.2.

Table 2.2: Standard Quality of Latex Concentrate

No	Parameter	Content
1	Dry Rubber Content (DRC)	60.00 (%), min
2	Total Solid Content (TSC)	2 (%), above DRC
3	Volatile Fatty Acid (VFA)	0.05 (%), max
4	KOH value	0.85 (%), max
5	Mechanical Stability Time (MST)	Minimum 650 second
6	NH_3 content	0.65-0.75 (%) for HA Latex Concentrate 0.2-0.29 (%) for LA Latex Concentrate

Source: Thaitex (2012)

The parameters as depicted in Table 2.2 comprises the following:

- *Dry rubber content (DRC),* to show rubber content in latex by coagulating latex with acetic acid. The standard method is as described in ISO 126 (1982).
- *Total solid content (TSC),* to show non volatile matters in latex at temperature from 70-100 ^{0}C at atmospheric pressure. The difference between TSC and DRC is known as non-rubber content. There is a correlation between TSC and MST i.e., higher TSC result in lower MST.

- *Volatile fatty acid (VFA) value*, to show carbohydrates and amino acids have already been converted into acetic acid, formic acid and propionic acid by bacteria. Increase in VFA will decrease MST. The standard method is as described in ISO 506 (1992).
- *KOH value*, to show ammonium acid radicals in latex. The standard method is described in ISO 127(2012)
- *Mechanical stability time (MST)*, to show the time required for first coagulation of rubber particles, and it measures the resistance of latex destabilizing by mechanical agitation. MST will increase in storage with addition of soaps of fatty acid. Hydrolysis of lipids will increase fatty acid, followed by increase in negative charges, and then the electrical double layer repulsion will become high, and this all will increase MST. The standard method is as described in ISO 35 (2004).
- *Ammonia content (NH_3)*, to show the types of latex, such as high ammonia (HA) or low ammonia (LA).

2.4. Skim Latex

According to Mahat and MacRae (1992), skim latex contains non rubber fraction with a large watery fraction known as natural rubber waste serum (NRWS) and contains 5% dry rubber content (DRC) and about 7% total solid content (TSC). NRWS contains various water-soluble, non-rubber substances of which the pseudo-sugar, quebrachitol (2-0-methyl (–) - chiroinositol or 2-0-methyl inositol), which is most prominent, water, nitrogenous materials, fatty acids and ash components as shown in Table 2.3.

Table 2.3: Chemical composition of natural rubber waste serum (NRWS)

No	Components	Composition on dried solid (%)
1	Water	5.5
2	Nitrogenous materials	47.2
3	Sugar and pseudo sugar	30.1
4	Ash components	16.7
5	Fatty acids	0.5

Source:Mahat and MacRae (1992)

Dry rubber in skim latex will coagulate with and without acid such as sulfuric acid or formic acid. According to John (2011), for innovation in coagulation process, acid should not be added to prevent acid contamination in the effluent. In conventional process of coagulation, acid is used to coagulate the latex, and it has been found to affect the environment.

There are several chemicals added to the natural rubber latex such as: ammonia, TZ (tetra methyl thiuram disulfide - zinc oxide), formic acid, ammonium laurate, di-ammonium phosphate, lauric acid and sulfuric acid.

Properties of preservatives in natural rubber latex concentrate processing are as follows:

- Ammonia

  Ammonia is used to prevent coagulation of latex. Ammonia (NH_3) is a colorless gas, boils at -33.34 °C, and is considered quite hazardous. It is also used as building block for the synthesis for many pharmaceuticals. Ammonium hydroxide (NH_4OH) or household ammonia is a solution containing 5% to 10% by weight of NH_3 in water (OSHA, 2013).

- Tetra methyl thiuram disulfide (TMTD)

  Tetra methyl thiuram disulfide $((CH_3)_2NCS_2)_2$ is usually used as a fungicide, seed disinfectant, insecticide, and bactericide. It is a white crystalline powder, and classified as rubber accelerator (Chemicalland21, 2013).

- Zinc oxide (ZnO)

  Zinc oxide, is commercially produced synthetically and is widely used as an additive in several processes in ceramics, glass, cement, rubber manufacturing (IZA, 2011). It is soluble in water, alcohol but insoluble in most acids.

- Diammonium hydrogen phosphate (DAP), $(NH_4)_2NHPO_4$

  Diammonium hydrogen phosphate serves as an anti-fungal, and in some plant, it is added to latex while still in the plantation. Besides, DAP is used as fertilizer and fire retardant. As fertilizer, DAP will increase soil pH.

- Formic acid

  Formic acid (also known as methanoic acid) HCOOH, during the natural rubber latex concentrate processing is used to coagulate a liquid (skim serum) that separate from centrifuge in the secondary pond. Coagulate product is used as raw material for block skim rubber processing. Formic acid occurs naturally and as intermediate substances for chemical synthesis (University, 2013).

- Lauric acid

  Lauric acid (also known as dodecanoic acid), is a saturated acid that has antimicrobial properties.

- Sulfuric acid (H_2SO_4)

  Sulfuric acid is a strong acid, and is soluble in water at all concentrations. It is used in natural rubber latex concentrate as coagulant to separate rubber from the liquid (skim serum). The effluents resulting from rubber processing have been shown to have high pollution potentials caused by the presence of components such as phosphates and nitrates which will increase the nutrient value of water bodies (Atagana, 1999). Algae bloom will appear, thus the ecological balance of the water system will be disturbed.

Nowadays, increasing demand of chemical products has created a bad perception in the community because it will reduce the quality of life. Based on research, this resulted in high costs due to waste generated and can reach as high as 40% of production costs (Clark, 2005). This is marked by changes in industry behavior in the 20th century and the 21st century which in some ways focus on reducing the impact to the environment. It should be done by using biodegradable materials, short stages of processes.

There are some common thread that links how to get a process that will produce a product that has full commitment to environmental stability. Also there are several parties that are interconnected to create these conditions, in particular government and industry. Industry has the main aim that a process will produce products with maximum profit, use of minimum and maximum natural resources compliance to government rules. On the other hand, the government is faced with a reality that the industry can employ labor, tax sources to run the government, however the industry can also cause environmental damage. Hence, the government should have rules which support industrial activities without causing environmental damage and could be quantified. Eco-efficiency is a term that connects both economic and environmental parameters.

2.5. Eco-Efficiency

There are four different types of environmental technology: end of pipe technologies, integrated technologies, eco-efficiency technologies and new system designs. Eco-efficiency technologies and new system design are selected because of high potentials application (Bleischwitz, 2002).

Eco-efficiency is a concept that connects environmental and economic on how industries get the benefits with minimal impact to the environment. According to FIFA (2003), cost will be reduced and increased competitiveness will be achieved through realization of eco-efficiency and finally companies can realize better environmental outcomes. Basically eco-efficiency indicate *doing more with less* – by using resources more efficiently; it can improve environmental performance by reducing materials, energy and other natural resources while minimizing cost and liabilities.

Concept of eco-efficiency refers to Vervaillie and Bidwell (2000) was developed by the World Business Council for Sustainable Development (WBCSD) in 1992 and has been largely accepted by the business world.

WBCSD defines eco-efficiency as: "Eco-efficiency is achieved by the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the earth's estimated carrying capacity.

In 2000, WBCSD introduced 3 objectives of eco-efficiency through decreasing resource consumption, decreasing impact to environment and providing high product or service value. Generally, the purpose of these objectives are to offer opportunities for business savings (Canada, 2002). According to WBSCD (2000), eco-efficiency should increase recycling, improve product life, minimize damage to water body, minimize air emission, minimize waste disposal and dispersion of toxic materials and generate greater profits in accordance to its functionality.

The three objectives of eco-efficiency were detailed by WBSCD in 2001 by introducing 7 elements:

1. Reduce material intensity: reduce in material use such as raw material and chemical substances and should generate less waste.
2. Reduce energy intensity: reduce the energy intensity before, during and after processing
3. Reduce dispersion of toxic substances
4. Enhance material recyclability
5. Maximize sustainable use of renewable resources
6. Extended product life (durability)
7. Increase service intensity: increasing the service intensity of goods and services

According to WBCSD, reducing impacts to environment will enhance resource productivity, and ultimately create benefit for competition.

2.5.1. Eco-efficiency in global business

Firms that use eco-efficient strategies will reduce costs and increased profits than similar firms that do not adopt eco-efficient business strategies (Sinkin, 2008). Tahara et al., (2005) used concept of eco-efficiency to define ”total CO_2 efficiency”, ”direct CO_2 efficiency”, and “indirect CO_2 efficiency” using Input-Output (I-O) table analysis for the evaluation of companies and industries and found that total CO_2 efficiency of industries were lower than companies. Figure 2.1 shows the setting of boundary for CO_2 efficiencies. Industries are refers to service industries, assembly industries, and primary industries, whereas companies are refers to public services and medical services.

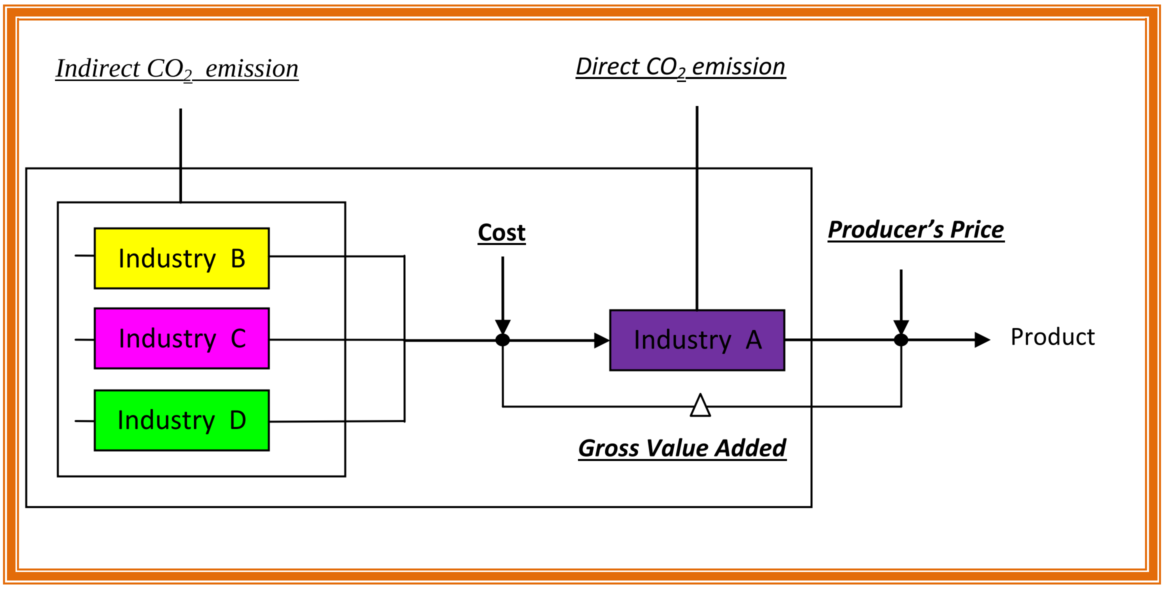

Figure 2.1: Boundary Setting of CO_2 Efficiency
Source: Tahara et al., (2005)

According to Amemiya et al. (2008), recycling waste of main products should decrease the effect of environmental burdens by substitution or reuse for another process. By recycling, eco-efficiency study shows higher conversion or yield and more energy saving. Eco-efficiency can be performed by process modifications or improvements or technological innovation, or also finding alternatives in order to create more value with lower environment impact.

2.5.2. Eco-efficiency in Indonesia

Environmentally sound development is in accordance with the mandate of the laws and regulations in Indonesia that is intended to provide the greatest possible benefit to the surrounding environment affected by an activity. Another expected benefit is also in social aspect that is for safety, comfort and welfare of the society.

Although all the elements of eco-efficiency is still not fully implemented, but basically the government has begun implementing eco-efficiency concept. This can be seen from the government regulations on quality standards requirements for air emissions, and wastewater of various types of industries.

According to Said (2002), the implementation of eco-efficiency concept in Indonesia has been widely encouraged in agro industry sector. This concept aims to increase resource productivity. The implementation of eco-efficiency has been initiated for industries that are involved in palm oil, coconut and fishery.

Indonesia Water Resource Network (JSDA) (2010), conducted various seminars related to eco-efficiency. Discussion resolves around the management of water resources which should implement the concept of Green Growth to institutionalize eco-efficiency, particularly eco-efficiency in water infrastructure (BAPPENAS, 2010).

2.5.3. Measuring Eco-Efficiency

Eco efficiency is calculated as:

(Economic value added)/(Environmental impact added), (Eq.1)

and can be represented by

(Product or Service value)/(Environmental influence). (Eq.2)

According to WBSCD (2000), Dunning (2004), products or service value is adapted to the business that can be operated: quantity of goods or services produced or provided to costumers or net sales. Therefore it can be expressed in volume or mass of raw material or product of ongoing process. Besides, it can also be expressed as monetary, to show eco-efficiency is related to money. Meanwhile environmental influences can be divided into two parts: environmental influences during service creation and during service use. Environmental influences during service creation involve the use of materials, energy consumption, water consumption and emissions. Environmental influences during service use concern on packaging usage, energy consumption, and emissions during use. Taeko et al., (2004) mentioned that in Japan, product value can be shown as functions and performance. Tabel 2.4 shows components as a function of product value (numerator).

Table 2.4: Example of an Eco-Efficiency Indicator – Product value (Numerator)

Item	Product examples	Examples of items applied
Physical quantities	-	Amount of sales, production volume (units, kg, tons, etc.)
Economic value	-	Amount of sales, profits or income (currency)
Functions and performance	Refrigerators	Capacity, cooling speed, freezing speed
	Personal computers	MPU professing capacity, hard disk capacity
	Scanners	Optical performance, media processing performance, data processing performance
	Washing machines	Washing capacity, product service life
	Printers	Printing speed, image quality
	Radiators	Ease of disassembly, product service life, number of parts
	Cell phones	Calculation speed, memory, LCD, battery

Source:(JEMAI, 2004)

Kharel and Charmondusit (2008), studied the comparison and characterization of eco-efficiency each year in iron rod industry by reducing the consumption of resources and energy. Quantitatively, eco-efficiency that is calculated by general formula (Eq.2) showed that eco-efficiency are increased due to process modification such as installing heat recovery unit.

2.5.4. Eco-Efficiency Indicator

The National Round Table on the Environment and the Economy, NRTEE (2001) identified three indicators for eco-efficiency i.e., waste intensity indicator, energy intensity indicator and water intensity indicator. Rattanapan, et al., (2012), suggested environmental indicators to show eco-efficiency are material consumption, energy consumption, water consumption, waste water consumption, solid waste consumption and greenhouse gas emission. Energy, waste, and water have been used by many companies to identify efficiency or the performance of the process. These components support the concepts of WBCSD, which referred to concept number 1 reducing material intensity and concept number 2 reducing energy intensity.

2.5.4.1. Energy Intensity Indicator

Energy intensity indicator measures all fuels consumption before, during and after processing. Energy intensity indicators can be in the form of electricity, oil, gas, coke, coal, wind, and nuclear.

$$\text{Energy intensity} = \frac{\text{energy consumed within the project boundary from all sources}}{\text{unit of production or service delivery}} \quad \text{..... (Eq.3)}$$

According to Zhang et al., (2013), unit operation and integrating the whole of unit operation could be the potential energy efficiency improvements in chemical process. Unit operation will design equipments with optimal condition of operation and using system engineering or process integration technology to integrate the whole unit operation.

2.5.4.2. Waste Intensity Indicator

Waste is all output which exclude the main product or by product at one particular process. The indicator measures the total material entering the boundary minus materials that ends up in the product and by-product per unit of production or service delivery.

$$\text{Waste intensity} = \frac{(\text{total material entering the boundary} - \text{material in main and by product})}{\text{unit of production or service delivery}} \quad \text{..... (Eq.4)}$$

or

$$\text{Waste intensity} = \frac{\text{total waste leaving the project boundary}}{\text{unit of production or service delivery}} \quad \text{...... (Eq.5)}$$

2.5.4.3. Water Intensity Indicator

Generally, for industries, water is consumed in office, processing, cleaning, utilities, and domestic sections. Industries today are concerned with in water consumption, because water price is very expensive and it is needed to minimize water consumption. Many ways have made by the industries according to availability and quality (Unilever, 2012). Unilever has made water savings about 10 % per ton of production in 2011 compared to

2010. This is done, among others, by water audits, advanced control and integration of cooling and cleaning systems, investment in water treatment technologies to enable water recovery and reuse, and also rainwater harvesting (Unilever, 2012).

$$\text{Water intensity} = \frac{\text{water taken into boundary}}{\text{unit of production or service delivery}} \qquad \ldots \text{(Eq.6)}$$

2.6. Routes To Eco-Efficiency

There are 10 types of management tools to improve the quality of products and profit by developing environmental management which involves:

2.6.1. Cleaner production

Cleaner production is a preventive action, intends to minimize waste and emissions and maximize product output by considering the environment aspects since raw material, processing and consumption stages. It is intended to: choose raw materials that contribute less impact to environment, making material and energy balances of the process will produce cleaner processing. Cleaner production considers the entire life cycle of products (EPA, 2007) including modifying process, selection of raw materials, optimizing the use of energy and raw material, on site recovery and recycling, and managing all used products in its life cycle.

Cleaner production reduces production cost, increases competitiveness of new and improved technologies, reduces risk from site treatment, storage and disposal, improve health and safety, etc.

Cleaner production and eco-efficiency has a symbiotic relationship, in which eco-efficiency focusing on the strategic side of business as value creation and cleaner production on the operational side of business as production (van Berkel, 2007).

2.6.2. Environmental management system

The first Rio Summit held in 1992 resulted in a commitment towards protection of the environment across the world. An Environmental Management System (EMS) is a set of processes and practices that enable an organization to reduce its environmental impacts and increase its operating efficiency. EMS contains procedures which identifies the impact to the environment and describe how to manage the company (USEPA, 2012).

The company's commitment will be shown by certification of its EMS to the ISO 14001 standard. EMS will assist the company responsibility and commitment for the future condition by reducing damage to the environment, which relates well to eco-efficiency concept.

2.6.3. Environmental auditing

Environmental audits evaluates sets goals for the future ecological performance and handles freely, objective, credible and this transparently. Today many companies use environmental audits as a tool to determine compliance to attain a clean environment. Environmental audit listed in ISO 19011 (2002), among others contains the basic instructions on auditing, program management, environmental management system audit.

Environmental audit is used as a tool to assist in assessing the condition of a company's environmental management systems, to reduce risks to the environment caused by the activities.

2.6.4. Public environmental reporting

Any activity that would cause impacts to the environment should be reported or made some form of a report which aims to determine the impact of activity level, so that the community and the government can monitor. Reporting aims to determine the characteristics of activities and can be done periodically for the parameters that have a tendency to damage (PSA, 2006).

According to Natural Heritage Trust (2000) there are some benefits by doing public environmental reporting i.e.: increasing marketing chance, to intensify commitment, to enhance relationships between government who executes the regulation, industry and non government organization.

2.6.5. Design for environment

Planning stages of process or choosing of material are important, which the goal is to reduce the environmental impact of the process. The design can be done by minimizing the use of materials, reusable or recyclable. Based on this information is seen that the design for the environment supports eco-efficiency concepts.

2.6.6. Product stewardship

The industries are the parties that contribute damage the environment. Therefore, the industries have huge responsibility for maintaining environmental balance (EPA, 2005, 2012).

Product stewardship is done to protect the environment using product centered approach. Thus, product stewardship should reduce the impacts of products since processing until disposal. Product stewardship is also known as extended product responsibility, is a shared responsibility in the product life cycle of the whole chain. Stakeholder involved in the activity include designers, manufacturers, retailers, consumers, waste managers and disposers to reduce impacts to the environment.

2.6.7. Life Cycle Assessment

According to Das (2005), Life Cycle Assessment (LCA) is a concept as well as a tool to determine the amount of burden to the environment as a result of human activity. The assessments of activities are reviewed from extraction until disposal, known as from cradle to grave. The activities are from extracting phase of raw material, production phase, distribution phase and use phase and disposal. Activities can also be reviewed between cradle to grave, known as the gate to gate, such as during processing. Material use, energy use and waste released to the environment are reviewed quantitatively and qualitatively. The advantage of using LCA principles helping decision makers to choose a series of activities that will give the smallest effect to the environment.

LCA has been standardized as a new standardization by the International Organization for Standardization, ISO 14040 includes Principles and Framework and ISO 14044 includes Requirements and Guidelines (Finkbeiner, 2006). These new standardizations changed Life Cycle Impact Assessment (LCIA) to the new standards.

Life cycle impact assessment (LCIA) is a tool to identify the impact of a product, process or service over its life cycle by identifying quantitatively the energy and materials used, and wastes released to the environment.

2.6.8. Supply chain management

A *supply chain* is a network of facilities and distribution of products from raw material until finished products to the customer. According to Ganeshan and Harrison (1995), this network are varies between industry or firm and is a combination of art and science to improve the industry. Planning, source, making, delivering and returning are five basic components of supply chain management. Planning will result in less cost and more efficient by monitoring supply chain. Source continuity should be maintained and make scheduling for the activities from production until delivery. Industry should have a good solution for the consumers and be able to accept return for the excess or defect product. These five components support eco-efficiency.

2.6.9. Environmental accounting

Process industry will deliver results in the form of main products and by-products. By products usually give lower value than the main product. Sometimes byproducts can be converted to some monetary value but it often becomes a burden to the environment as a waste. As a waste by product, this potentially could damage the environment. Accounting must be done to obtain environmental burdens of the activities, so as to given information on how eco-efficient the activities are.

2.6.10. Ecological Footprint

Ecological footprint is a quantitative measure showing the appropriation of resources by human beings (Klemes and Cucek, 2013) and based on Global footprint network (2012), ecological footprint will measure the amount of resources use and the amount of waste which is released to the earth using prevailing technology. According to Teijin (2012), eco footprint can also be interpreted as the cost of conducting the activities. The environmental costing is kept to a minimum, therefore the company can compete with similar activities from other companies. Activities are assessed using life cycle analysis and eco-efficiency analysis.

It can be concluded that in the global trend there are various assessment tools and system which has been adopted and proven. Therefore industry should taken up a step to adopt these tools for better management in industry, manufacturing and services.

2.7. Life Cycle Assessment (LCA)

People today are concerned with the issue of environmental degradation and decrease of natural resources. In turn this causes entrepreneurs to improve, among others company trends by implementing greener processes, starting from selecting raw materials, processing, and packaging, to transportation. Prevention the pattern of activities carried out the benefits and improving environmental performance simultaneously.

According to UNEP (2004), life cycle thinking is one of the main ways to reduce emission to environment by reducing resource use and also to enhance performance of socio-economic through life cycle. Life cycle perspective helps ensure that the activities are environmentally sound, have competitive advantage, reduce costs, and designing a result in better product.

LCA is currently regulated in ISO 14040 (2006) and ISO 14044 (2006). ISO 14040 is about the technical requirements which describe the principles and framework and ISO 14044 is about requirements and guidelines. The structure of life cycle assessment is as shown in Figure 2.2.

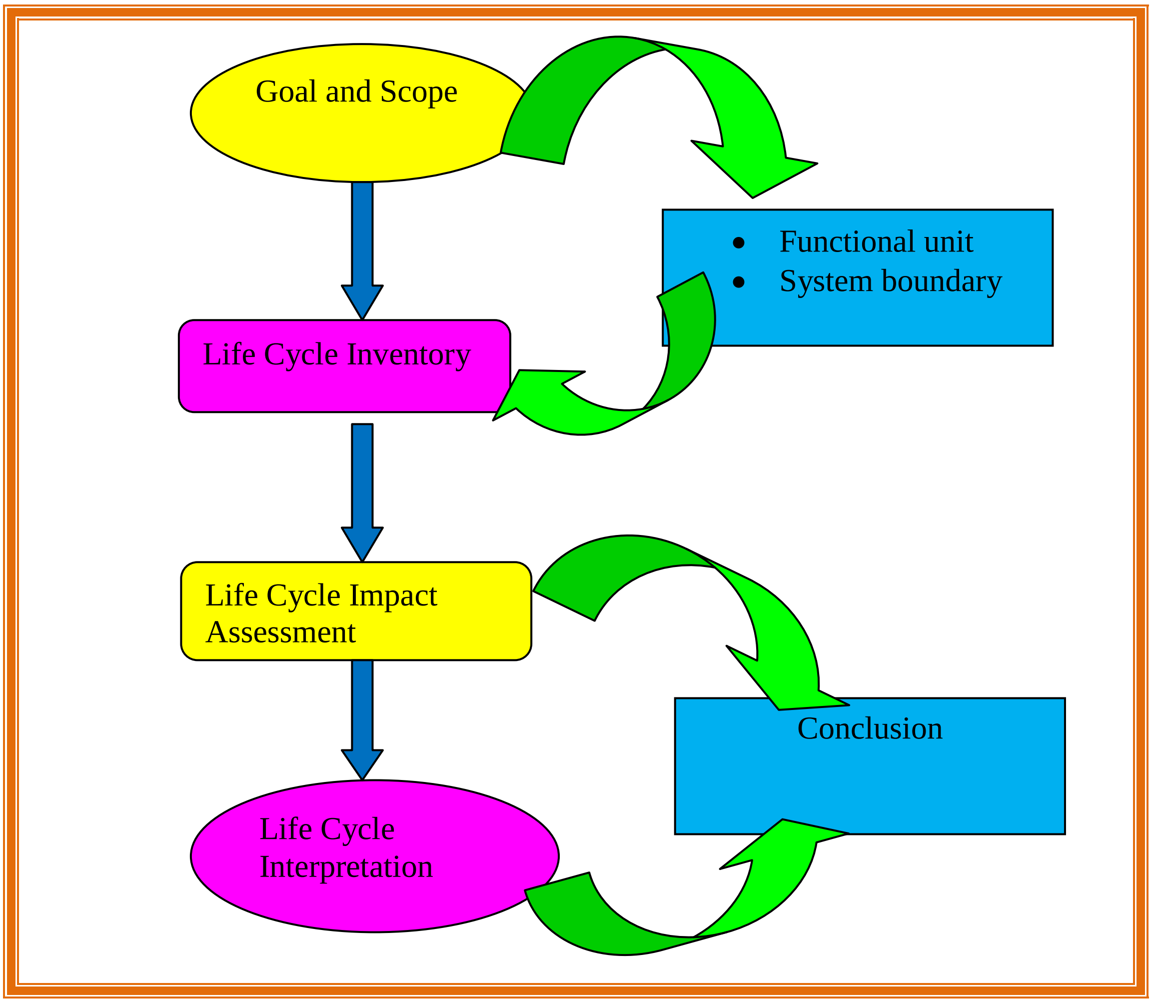

Figure 2.2: Structure of Life Cycle Assessment
Source: ISO 14040 (2006)

2.7.1. Goal and Scoping

Goal and scope is needed to limit the issues to be discussed which consists of the purpose of doing LCA and the limits of the methodology to be used. Functional unit will show the magnitude of the activities carried out, can be expressed as a unit of time, flow rate, and system boundary will limit activities that will be reviewed.

2.7.2. Life Cycle Inventory

Life cycle inventory aims to collect all the data input-output that are relevant to a system.

Steps of life cycle inventory include (Das, 2005):

a) Developing flow diagram that will show and explain stages of process, material and energy balances. Stages in life cycle inventory are according to system boundary.
b) Planning for data collection because it is very important to obtain accurate data.
c) Collecting data: data that should be collected primarily in this research involve material balance, chemical using, energy balance and water balance, air emission, wastewater and secondary data such as site visit and interviewing experts in the same plant.
d) Evaluating of accuracy of all data that have been collected.

2.7.3. Life Cycle Impact Assessment

Life Cycle Impact Assessment is an assessment of the impact that occurs in the environment and on human health due to an activity during the life cycle inventory.

Steps of life cycle assessment consist of (Das, 2005):

a. Select and define impact categories that relate with goal and scope
b. Classification to assign life cycle inventory results to the impact category
c. Characterization to know impact categories based on life cycle inventory
d. Normalization to compare impact categories on each other by dividing indicator result to a reference value
e. Grouping to rank the indicator of impacts
f. Weighting to compare impact categories on each other based on importance or relevance
g. Evaluating the potential impact after calculating selected category of impact.

Life cycle impact assessment is a step to evaluate the impact of inventory phase after calculation, such as damage assessment and impact categories. Eco-Indicator 99 is chosen because this methodology is more complete in its impact categories compared to others; such as CML 92, Eco-Indicator 95. Impact assessment will be characterized by calculating or quantifying the effect of burdens to environment. Eco indicator 99 methodology calculate indicator scores to construct an environmental assessment through impact assessment of the activities. The higher the indicator, the greater the environmental impact (Baayen, 2000).

The resulting scores present a suggestion for product enhancement.

According to Eco-Indicator 99, three types of environmental damage should be evaluated: human health, ecosystem quality and resources. Selection of impact categories involves,

- Damage assessment of human health: respiratory organic, respiratory inorganic, carcinogen, climate change, ozone layer depletion.
- Damage assessment of ecosystem quality: acidification or eutrophication and land use.
- Damage assessment of resources: mineral and fossil resources.

Damage to Human Health are stated in Disability Adjusted Life Years (DALY), and build on for carcinogen effects, respiratory effects, ozone layer depletion, climate change and ionizing radiation.

Damages to Ecosystem Quality are expressed as Potentially Disappeared Fractions (PDF), and shows disappearance of species in a certain area, because of environmental issues. The damage is obtained by multiplying the PDF values to the area size and the time period.

Damage category Ecosystem Quality consists of ecotoxicity, acidification and eutrophication, land use and land transformation. Ecotoxicity is expressed as the percentage of all species present in the environment living under toxic stress (Potentially Affected Fraction or PAF). PAF is a toxic stress, not observable damage should convert into real observable damage, i.e. convert PAF into PDF.

Damages to Resources are expressed as the surplus energy for the future mining of the resources (as minerals and fossil fuel).

2.7.4. Life Cycle Interpretation

Life cycle interpretation is used to analyze and to assess the information generated from the calculation of life cycle impact assessment (LCIA) based on the data contained in the life cycle inventory (LCI). Conclusion obtained produce recommendations which are reported in a transparent and consistent in accordance with the goal and scope.

CHAPTER 3

RESEARCH METHODOLOGY

3.1. Introduction

This chapter presents the framework that will support the methodology to be conducted to achieve the objectives as listed in section 1.3. The activities involved are as shown in Figure 3.1

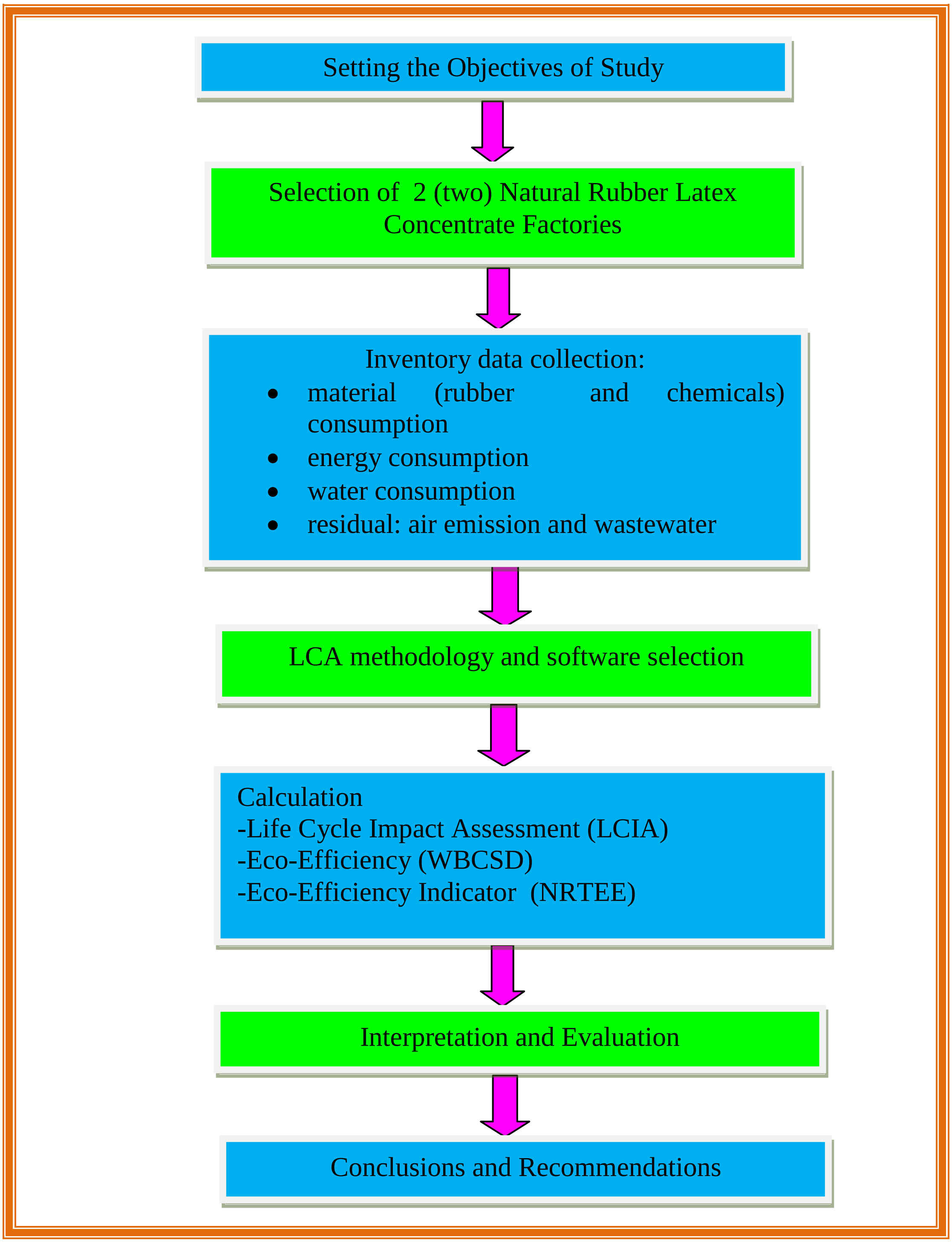

Figure 3.1: Framework and Stages of Research Methodology

3.2. Setting the objectives of the study

The framework and stages of this study are based on the ISO 14040 and Eco-Efficiency principles.

3.3. Selection of 2 (two) Natural Rubber Latex Concentrate Factories

According to Haris (2010), currently there are fifteen latex concentrate factories in Indonesia. Latex concentrates produced from natural rubber are commercially available as High Ammonia (HA) latex concentrate and Low Ammonia (LA) latex concentrate. Concentration of ammonia in High Ammonia latex concentrate is 6.0 -7.0 g NH_3/ liter of latex and 4 -5g NH_3/ liter of latex for Low Ammonia latex concentrate. HA latex concentrate is used to produce foam products, dipped goods, adhesives, elastic thread, household and industrial gloves, balloons, rubber bands and finger cap. LA latex has several advantages which include better quality, lower cost of production by way of savings in preservatives, acid and lower cost of effluent treatment (INR, 2012).

Ammonia is added during the process to enhance the preservation of latex but depending on specific requirements of the customer, various amounts are added to the concentrated latex.

The scope of this study covers high ammonia latex concentrate processing since most of the latex concentrate production in Indonesia produces HA latex concentrate. Production of latex concentrate in Indonesia is 42,480 ton each year and mostly for HA latex concentrate (Haris, 2010). This is because of the difficulty to maintain the stability of LA latex concentrate. Selection of Factory A and Factory B for this study is based on:

3.3.1. Location of the factory

Factory A and Factory B are located in North Sumatera, Indonesia. Thus it is expected that the composition and substances of natural rubber are generally the same. Hence information on the existing results are based on the differences in the processing of the field latex.

Factory A is located in the city of Tebing Tinggi which is 60 km away from the city of Medan at an altitude of 26 –34 m above sea level. Factory B is located at a distance about 80 km from the city of Tebing Tinggi or 140 km from Medan at an altitude of 3 m above sea level. Figure 3.2 shows the location of the two factories.

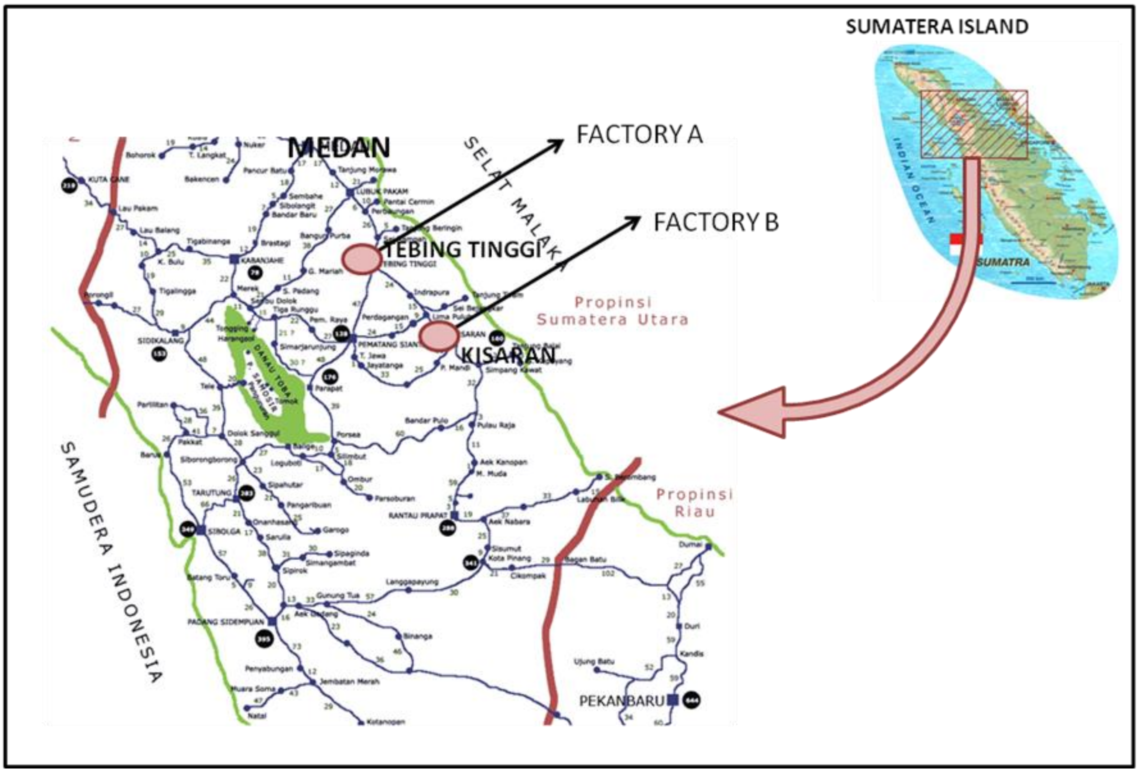

Figure 3.2: **Location of the Natural Rubber Latex Concentrate Factories**
Source:Asia Maya.com- Sumatera,(2012)

3.3.2. The process and product

The two factories chosen produce latex concentrate as the main product and skim latex as by-product and both use centrifugation as a separation process. There are ancillary equipments and chemicals to support the operation of the whole process. In addition there are also variations in the amount and types of chemicals used, which may result in differences in the quality and quantity of the product. Figure 3.3 shows the scheme of separation process in natural rubber latex concentrate.

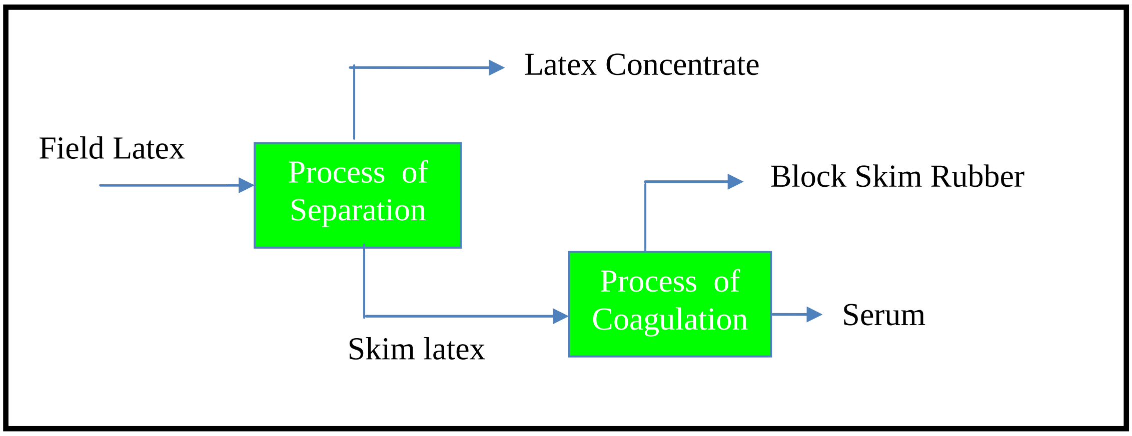

Figure 3.3: Process Separation Scheme of Field Latex

3.3.3. Data availability

Basically, data availability is one of the reasons in the selection of factories. Adequate and accurate data are expected to be the basis for the achievement of the existing objectives described in Chapter 1.

3.4. Inventory Data Collection

Inventory data were collected to get an overview of the process for each factory. Data collected include materials (rubber and chemicals) consumption, energy consumption, water consumption, air emission and wastewater quality. The flow diagram of the overall process of natural rubber latex concentrate is shown in the Figure 3.4

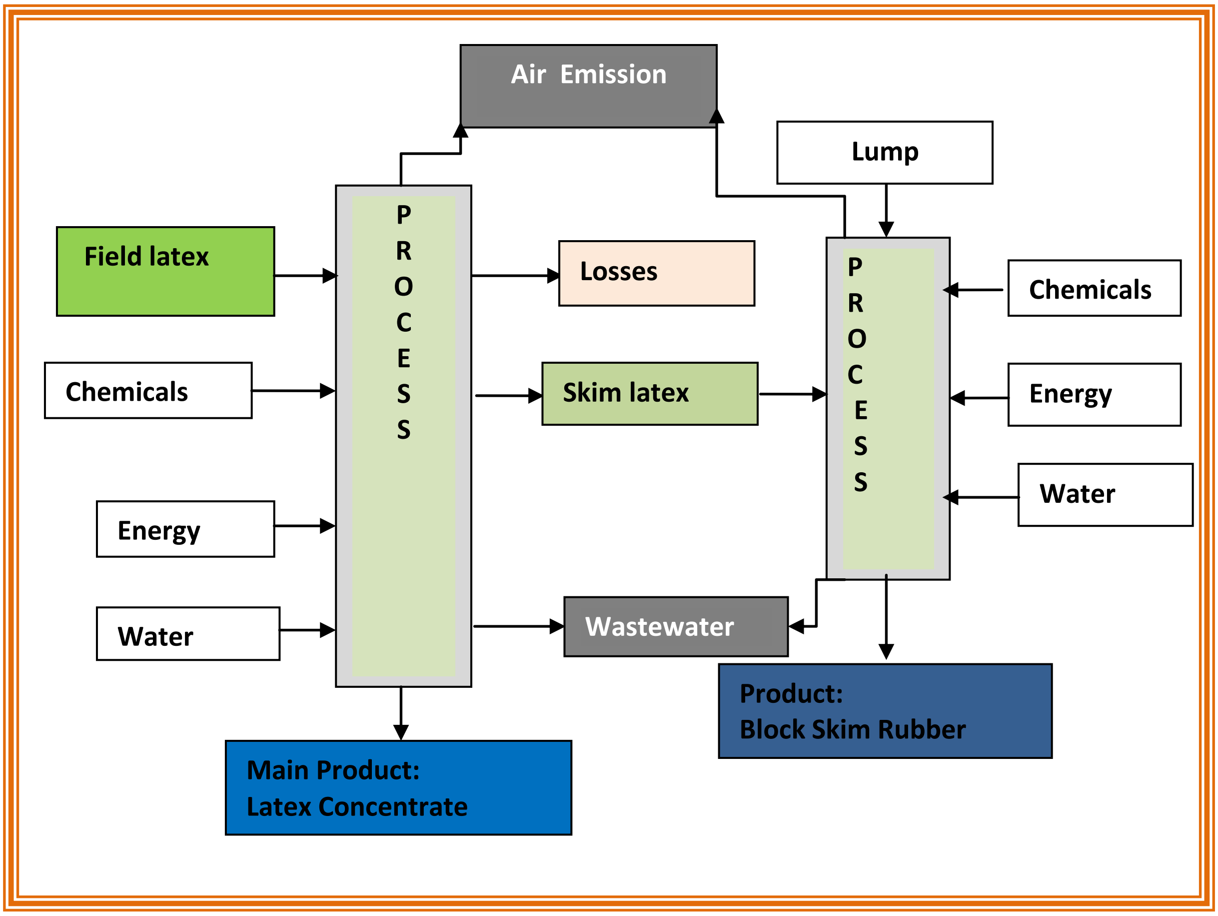

Figure 3.4: Overall Process Flow in Natural Rubber Latex Concentrate Processing

3.4.1. Material Inventory

Materials were divided into two parts, rubber balance and chemical consumption.

3.4.1.1. Rubber

Rubber balance is made to determine the concentration or amount of overall dry rubber which will show the amount of rubber in the input and output of the process. Figure 3.3 shows that the input of the process contained rubber with known composition from laboratory analysis. The outputs that contain rubber such as in the pond, skim latex and losses were also obtained from laboratory analysis. Losses or waste were obtained by doing rubber balance which then give the efficiency and impact to environment from natural rubber latex concentrate processing.

Rubber balance will show the composition of rubber in field latex (input) and rubber output as main material in latex concentrate. The difference between rubber input and output in main product and by product is waste and will be used in eco-efficiency indicator determination. Data of rubber balance will be obtained directly from the records of the natural rubber factories.

3.4.1.2. Chemicals

Chemicals used in natural rubber latex concentrate processing have the ability to pollute the environment. These data are needed to evaluate the impact to the environment and will be obtained directly from the records of natural rubber latex concentrate processing.

3.4.2. Energy consumption

Energy in natural rubber latex concentrate processing can be divided into two parts, the energy used to produce concentrated latex and block skim rubber. The energy is required to move the rotator during mixing for the purpose of homogenizing the chemical preservatives and energy is also consumed in the centrifuge to separate rubber and non rubber. The equipments that consume energy in latex concentrate processing are onvangen tank, centrifuge, mixer and storage tank. Process production of block skim rubber also use energy to move the conveyor, for cutting tools, pressing, and in the drying process. The equipments that consume energy in block skim rubber are fan basin, macerator, creper, hammer mill, dryer and pressing. Energy consumption data is used to identify the impact to environment during process phase and obtained directly from the records in natural rubber latex concentrate processing. Energy consumption data will be used in energy intensity indicator as one of the indicators in eco-efficiency.

3.4.3. Water consumption

Most of the water is used to coagulate skim latex, others for cleaning the equipment and washing the rubber lumps from plantation and solid rubber from coagulation pond. Water consumption in natural rubber latex concentrate processing will be used to determine the impact to environment due to water consumption and to identify water intensity indicator in eco-efficiency indicator determination. Water consumption data will be obtained directly from the records of natural rubber latex concentrate processing.

3.4.4. Residual

The processing of natural rubber latex concentrate also produces some residues including gas, liquid and solid. Gas residue comes from chemical use, such as ammonia and fuel combustion. Liquid residuals known as wastewater mainly consist of water, which comes from cleaning of equipments in latex concentrate processing, washing the coagulum and rubber lumps and from latex itself in block skim rubber processing. Solid residue is rubber that did not participate as a product either in latex concentrate and block skim rubber. Solid are usually found in wastewater from coagulation pond have poor quality and sell at a lower price.

3.4.4.1.Gas

Gas as part of the residue in natural rubber latex concentrate processing will create air emissions. Air emissions are emissions generated during the process, which comes from stationary source, such as generator, dryer, and boiler. Air emissions data are obtained by direct measurement of parameters in accordance to the standard parameter set by the regulation of the Ministry of Environment Republic of Indonesia, Kep-13/MENLH/3/1995 on standards of quality for air emission from stationary source as shown in Table 3.1. These data are needed to determine if these emissions are still within the permissible limits. These data will also be associated with the impact on the environment as well as eco-efficiency in the natural rubber latex concentrate processing.

Table 3.1: Standards of Quality Air Emission from Stationary Source

No	Parameter	Standard Requirement(mg/m^3)
1	**SO_2**	1500
2	**NO_2**	800
3	**Particulate**	150

Source: *Ministry of Environmental Republic of Indonesia,(1995b).*

3.4.4.2. Liquid

Liquid as part of the residue is in the form of wastewater in natural rubber latex concentrate processing. Wastewater generated in natural rubber latex concentrate processing is managed to meet the established standards by Decree of Environment Ministry Republic of Indonesia, KEP-MEN LH-No 51, 1995, with regards to wastewater quality standard for industrial activities as shown in Table 3.2. Effluent data were obtained by taking samples on site at the last pond that are ready to be released to water body and the parameters are measured in the laboratory. These data re needed to determine the chemical content in wastewater and to determine if it is still within the permissible limits.

Table 3.2: Wastewater Standard Requirement for Industrial Activities

No.	Parameter	Unit	Standard Requirement
1.	pH		6-9
2.	BOD_5	mg/ L	100
3.	COD	mg/ L	250
4.	TSS	mg/ L	100
5	NH_3 Total	mg/ L	15
6.	N-Total	mg/ L	25

Source: *Ministry of Environmental of Republic Indonesia, (KLH, 1995a)*

3.4.4.3. Solid

Solid refers to rubber that did not contribute as a product either in latex concentrate and block skim rubber. In this research, solid waste is usually found in wastewater from coagulation pond and possess poor quality and thus sells at a lower price.

3.5. Life Cycle Assessment Methodology

In this study the environmental impact of natural rubber latex concentrate processing during the life cycle is determined by using LCA methodology that follow the ISO 14000 series. Among the software available at University of Malaya research group are Simapro 7, JEMAI, and GABI. Simapro7 provides more library function and thus able to provide more extensive data in this work compared to JEMAI and GABI. Some data were not found in GABI or JEMAI such as Diammonium phosphate, formic acid, sulfuric acid and zinc oxide. Thus Simapro 7, is used for calculation of environmental burdens during this study.

3.5.1. Procedure Life Cycle Assessment Methodology

3.5.1.1. Goal and Scope

The objective of the study is to assess the impact of water, energy and material uses and releases to the environment in natural rubber latex concentrate processing to produce latex concentrate and block skim rubber

3.5.1.2.System Boundary

The system boundary on natural rubber latex concentrate processing in this research is chosen from entry field latex into the factory until production of concentrated latex as the main product and block skim rubber as the by product. This system boundary is shown in Figure 3.5 for Factory A and Figure 3.6 for Factory B.

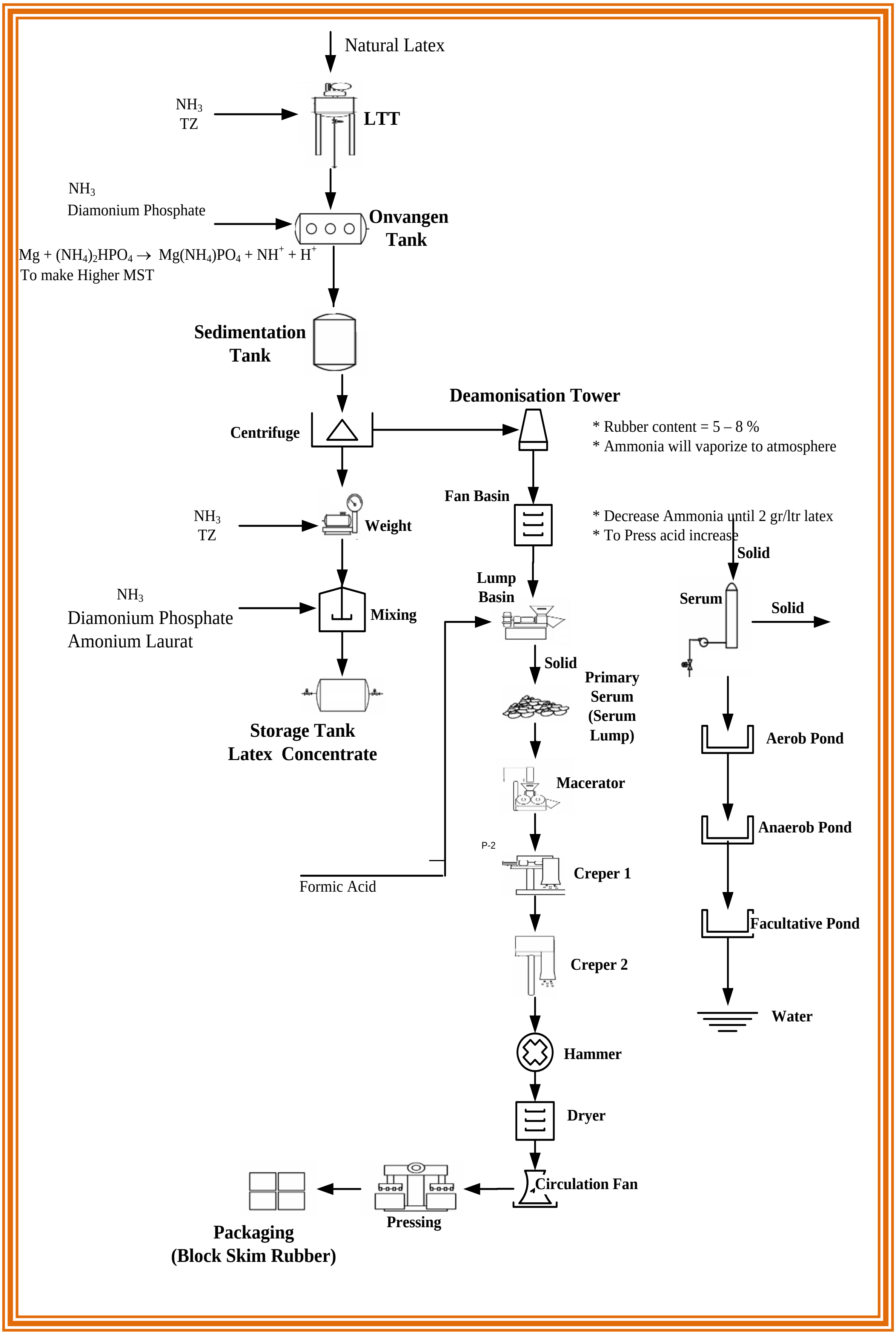

Figure 3.5: System boundary in Natural Rubber Latex Concentrate Processing in Factory A

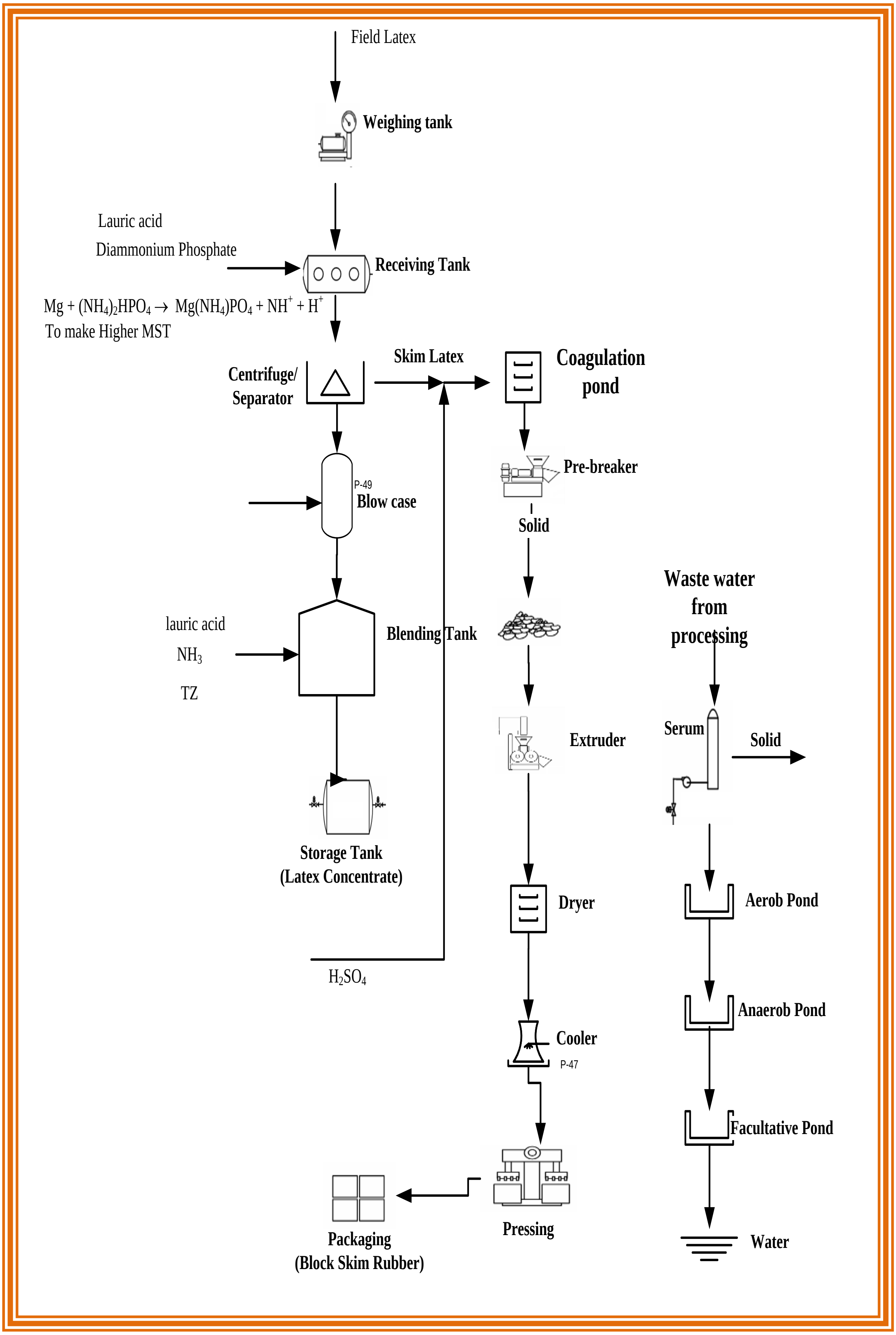

Figure 3.6: System boundary in Natural Rubber Latex Concentrate Processing in Factory B

3.5.1.3. Functional Unit

The functional unit of the study is to process 1,000 kg concentrated latex and 1,000 kg block skim rubber.

3.5.2 Life Cycle Inventory

Steps of life cycle inventory include (Das, 2005):

- Making flow diagram that will show and explain stages of processes, materials and energy balance. Stages in life cycle inventory is according to system boundary as shown in Figure 3.5 and Figure 3.6
- Planning for data collection; in this research collecting data such as rubber balance, chemical consumption, energy consumption and water consumption, air emission, wastewater quality
- Collecting data; data that should be collected primarily such as measuring air quality and wastewater quality and secondary data such as site visits and interviewing with experts in both factories.
- Evaluating all data that had been collected accurately.

3.5.3. Life Cycle Impact Assessment

Life cycle impact assessment is a step to evaluate the impact of natural rubber latex concentrate processing, such as damage assessment and impact categories.

3.5.3.1. Eco-Indicator 99

Eco-Indicator 99 is chosen for calculating impacts and damages to the environment because this methodology is based on the damage oriented approach (endpoint) and directly express environmental problem as it is (Reno, 2010). Hierarchical version (HI) is choosed as a damage model, because this version can be used in long and short term perspectives. HI commonly use in the scientific community and policy makers (M. Goedkoop, & Spriensma, R, 2001).

Three conditions affecting human and environment are used in this research. They are human health, ecosystem quality and sufficient supply of resources. Eleven impact categories were developed, namely carcinogen, respiratory organic and inorganic, climate change, ozone layer depletion and ionizing radiation, ecotoxicity, acidification and eutrophication, land use, land transformation, minerals and fossil fuel. Description of damages and impact categories are presented in section 2.7.3

3.5.3.2.Normalization

Damages and impact categories have different units, it can not be compared to each other directly. All components in damage assessment and impact categories can be compared each other through normalization procedure.

3.5.3.3.Weighting

Weighting is done by following the procedures from Eco-Indicator 99 to obtain the important categories after normalization and makes it possible to compare the categories directly. The unit of weighting is point where one point shows the weightage of impact from one mille-person equivalent (the impact per year on 1/1000 persons).

3.6. Eco-Efficiency Methodology

Eco-efficiency measurements on natural rubber latex concentrate processing use calculation as proposed by WBCSD and NRTEE for eco-efficiency indicators.

Based on WBCSD (2000) calculation, the numerator is the mass which in this case is the functional unit, with the reason this number remains constant as compared to monetary values which are always fluctuating. Economic value or price of natural rubber is not used because the price is always changing or fluctuates so it is difficult to make conclusions. The denominator selected are damages and impact categories that affect the environment by using eco-indicator 99.

Eco-efficiency with LCA based method will reduce eco-burden of the product and enhance the price in the market. Better characteristics are obtained with this two dimensional approach, resulting in lower cost at a higher value (Mestre, 2013).

According to WBCSD (2000) definition;

Eco-efficiency = (Mass)/(Environment influence or Environment burdens) …(Eq. 7)

Environmental influence or environmental burdens are defined according to eco-indicator 99 as follows:

a. Damage assessment

- Human Health
- Ecosystem Quality
- Resources

b. Impact categories that are included in the damage assessment are:

- Carcinogens
- Respiratory organics
- Respiratory inorganics
- Climate change
- Radiation

- Ozone layer depletion
- Ecotoxicity
- Acidification/Eutrophication
- Land use
- Mineral
- Fossil fuels

According to NRTEE (2001), eco-efficiency indicator in this research consists of energy intensity indicator, water intensity indicator, and waste intensity indicator. Energy data were obtained by calculating the energy consumed for every equipment. Water consumption was determined from the data in the factory and waste data was obtained by measuring the total rubber entering the system boundary minus the material that ends up in the product and co-product per unit of production.

$$\text{Energy intensity} = \frac{\text{energy consumed within the system boundary}}{\text{mass of product}} \quad \text{(Eq 8)}$$

$$\text{Waste intensity} = \frac{\text{(Rubber input–Rubber output) within the system boundary}}{\text{mass of product}} \quad \text{(Eq. 9)}$$

$$\text{Water intensity} = \frac{\text{Water taken in within the system boundary}}{\text{mass of product}} \quad \text{(Eq.10)}$$

3.7. Comparison between two factories

This study will compare primary data, environmental impact and the eco-efficiency from both factories.

3.8. Interpretation and evaluation of the result

Interpretation is made after calculation of the impact and eco-efficiency from both factories have been completed. This procedure is then continued by the evaluation step.

3.9. Conclusions and Recommendations

Conclusion and recommendations are presented after interpretation. Step has been completed.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results obtained following the procedure described in Chapter III. Discussion on the results are described in relation to the outcome of the study. Two factories that produce concentrated latex as the main product and block skim rubber as a by-product had been selected as test sites. Data were collected from both factories and subsequent calculations using Eco-Indicator 99 were made to determine the life cycle impact assessment. This step was followed by eco-efficiency calculation in order to compare benefits of the activities against the impact resulting to environment.

4.2 Products

Factory A produces 3 different types of products namely rubber thread, rubber gloves, rubber for export, while Factory B produces only a bulk intermediate product i.e. latex concentrate known as centrifuged latex (Cenex)^{TM}.

The specifications for field latex and products are as described in Table 4.1 and Table 4.2 for Factory A and Factory B respectively.

Table 4.1: Specification of field latex and latex concentrate for Factory A

Parameter	Specification			
	Feed (field latex)	Products (Latex Concentrate)		
		Rubber Thread	Rubber Gloves	Rubber for Export
Dry rubber content (DRC)	(28-30)%	(60-60.2) %	(60-60.2) %	(60-60.2) %
Volatile Fatty Acid (VFA)	≤0.050%	0.02	0.02	0.02
TSC		max 61.3	max 61.3	max 61.3
PNo (P number)	≤0.0250%			
NH_3	LA: 0.4-0.5% HA:>0.5-0.7%	4.5 g/ L latex	7-7.5 g/ L latex	LA: 2.5-3 g/ L latex HA: 7-7.5 g/ L latex
pH		9.90-10.20	10.50-10.90	10.50-10.90
Salts	0.5%	-	-	-
Carbohydrate	1.5%	-	-	-
Protein	1.6%	-	-	-
Water	±66.9%			
KOH number		0.60	0.60	0.60
Mechanical Stability Time (sec)		600	600	600

Source: *Factory A, 2008*

Table 4.2: Specification of field latex and concentrated latex for Factory B

Parameter	Specification	
	Feed (field latex)	Product (CENEX^{TM})
Dry rubber content (DRC)	30-35%	Min 60%
Volatile Fatty Acid (VFA)	≤0.050%	Max 0.02
PNo (P number)	≤0.0250%	
NH_3	(0.35-0.50)%	(0.75-0.84) g/ L latex
KOH number	-	Max 0.74
Mechanical Stability Time (sec)	-	Max 1600
Total Solid Content (TSC)	-	Min 2%
Copper content (ppm)	-	Max 8
Manganese content (ppm)	-	Max 8
Color (visual)	-	not blue or grey
Odor (neutralization with boric acid)	-	Odorless

Source: *Factory B, 2008*

As can be seen from Table 4.1 and Table 4.2 parameter specifications in each factory are different for both products and field latex. The main parameters for field latex are DRC, VFA, NH_3, while for products TSC, MST and KOH are also added. Generally for products parameters will be adjusted depending on the market requirements. Specifications for block skim rubber where the parameters of interest are similar for both factories are shown in Table 4.3.

Table 4.3: Specification of block skim rubber for Factory A and Factory B

Parameter	Maximum content
N	2.70%
Ash	1.00%
Volatile component	1.50%
Impurities	0.03

Source: *Factory A and Factory B, 2008*

4.3 Natural Rubber Latex Concentrate Processing

Both factories produce latex concentrate as main product and skim latex as a side stream using field latex as the feed material. Block skim rubber is produced from coagulation of skim latex known as coagulum mix with cup lump from plantation. This solidified rubber is another product sold by the two factories.

It is important to note that the main unit operation for concentrating field latex is centrifugation. There are minor differences in terms of other processing activities such as blending of chemicals and cutting up of solid rubber. Section 4.3.1 and 4.3.2 describe the actual process activities as practiced by Factory A and Factory B.

4.3.1 Processing in Factory A

4.3.1.1 Latex Concentrate Processing

Factory A processes 70,000 liter of field latex per day. The type of products generated will depend on the market demand. The description of the whole process of latex concentrate begins with the arrival of the field latex in tankers as described in Figure 4.1.

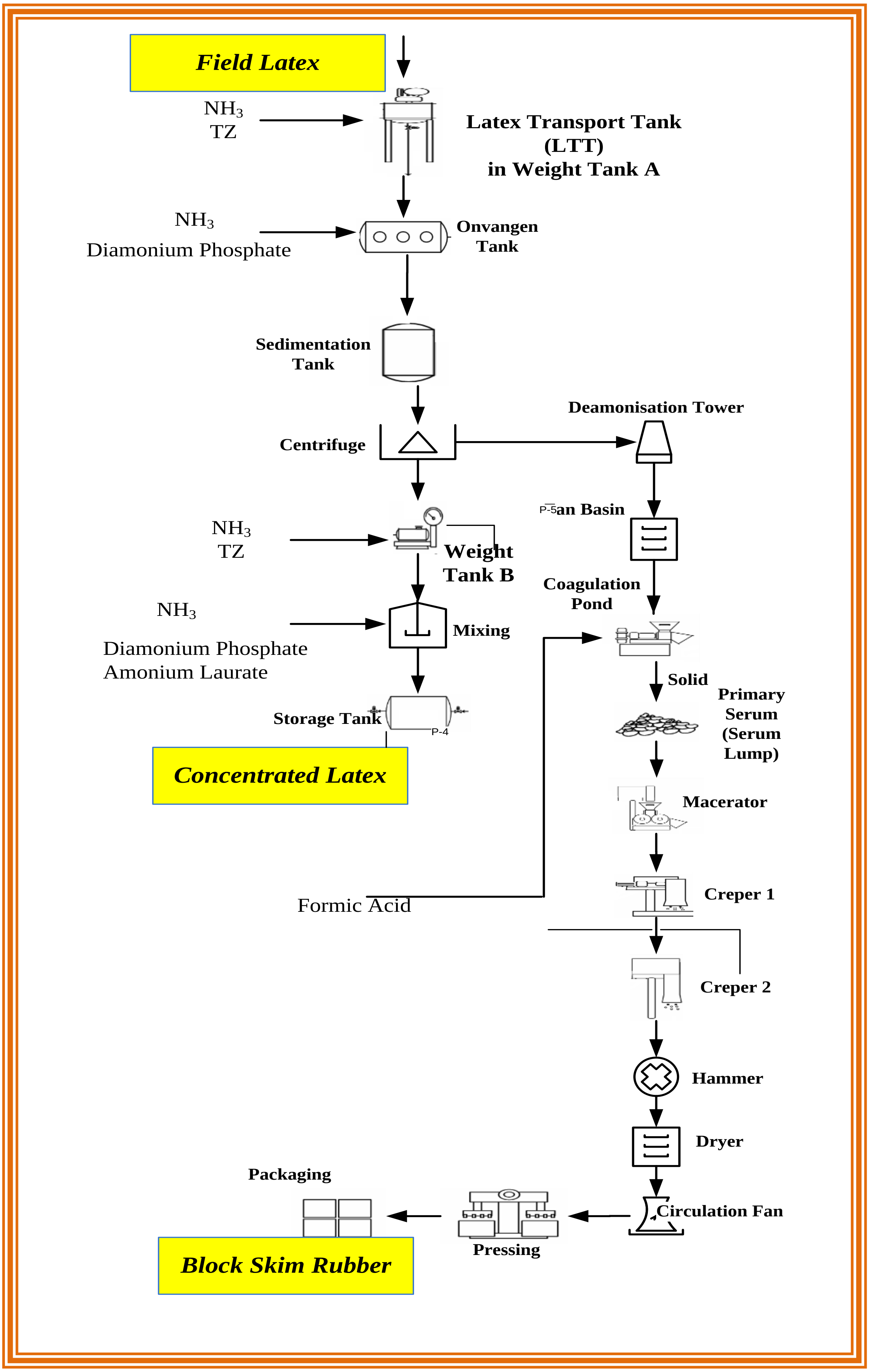

Figure 4.1: Flow Diagram Natural Rubber Latex Concentrate Processing in Factory A

i. Weighing

All field latex from the plantation is placed in Latex Transport Tank (LTT) and later weighed in the factory in order to determine the amount of field latex collected per day. Every LTT which delivers field latex to the Factory will be weighed using a weighing-bridge. The system boundary starts from this Weight Tank A.

ii. Latex Reception Area

Each and every Latex Transport Tank (LTT) arriving at the Factory will be sampled in order to analyze the concentration of dry rubber content (DRC), Ammonia (NH_3) and Volatile Fatty Acid (VFA). The specification of the field latex entering the factory has to meet the requirements in accordance with Table 4.1. The factory management will refuse the field latex consignment if the specifications fail to meet the criteria to meet the desired product quality and to avoid extra costs incurred due to the addition of chemicals.

Latex from LTT is pumped slowly into the receiving tank known as Onvangen Tank (OT) to avoid foam formation. Once again samples are taken from the Onvangen Tank to determine the DRC and NH_3 content.

For every input consignment, 1 ml of 10 % diammonium phospate (DAP) per liter field latex is added into Onvangen Tank to improve the mechanical stability time (MST) property. This procedure is necessary to eliminate Mg^{2+} and Ca^{2+} which are present in the latex. Mg^{2+} and Ca^{2+} can influence latex stability according to the following reaction :

$$Mg^{2+} + (NH_4)_2\,HPO_4 \rightarrow Mg\,(NH_4)\,PO_4 \downarrow + NH_4^+ + H^+$$

Ammonia will be added into the Onvangen Tank to prevent coagulation of latex. The amount of NH_3 added varies depending on the time before sedimentation stage as described below:

NH_3 : 5-7 g/ L field latex, for latex which is processed before 12 noon

NH_3 : 7-8 g/ L field latex, for the latex which is processed after 12 noon.

NH_3 : 8-10 g/ L field latex, when latex is processed after 24 hours from reception stage.

The difference in the amount of ammonia added depends on the interval between tapping and processing in the factory. Long intervals cause the increase in amino acids quantity due to the breakdown of the proteins in the field latex. Ammonia is added to deactivate the enzymes which break protein into amino acids.

Before sending to the sedimentation tank, the field latex is swirled for about 15 minutes to homogenize the field latex. Then sampling is conducted to determine the concentrations of total solid content (TSC), dry rubber content (DRC), ammonia (NH_3) and volatile fatty acid (VFA).

iii. Sedimentation

From the Onvangen Tank (OT), the preserved field latex is pumped in to the sedimentation tank and left for 2-3 hours to separate calcium (Ca) and magnesium (Mg) and other impurities such as carbohydrates and proteins. This sedimentation activity will increase the efficiency of the centrifuge and to improve the stability of concentrated latex. The sediment that is formed will be separated from the field latex and sent to secondary pond. The quality of latex is controlled in the sedimentation tank by periodic analyses in the laboratory, especially on VFA and NH_3.

iv. Centrifugation

The process of centrifugation basically is to separate the rubber from the non rubber contents, so that concentrated latex with the required properties is produced, namely, dry rubber content 60- 63% and density of 0.94 g/cm^3. Skim latex with DRC 5- 8%, density about 1.02 g/cm^3 is produced as a side stream which can be further processed into solid rubber.

During centrifugation, field latex flows by gravity through a feed tube into the plates of a bowl centrifuge which then flow through distributor tubes due to centrifugal force. As the bowl rotates, latex is dissociated into two fractions, a light dense concentrated latex and heavy dense skim latex (Figure 4.2). During this process DRC in the concentrated latex can be varied by adjusting the size of the hole of skim discharge (serum screw). In order to obtain concentrated latex with lower DRC and skim latex with higher DRC long serum screw is used. The length of the screw determines the distance to the center of centrifuge. If a higher value of DRC of concentrated latex is required, then a shorter serum screw can be used. Generally the efficiency of process can be calculated as :

$$\text{Processing Efficiency} = \frac{\text{Weight of concentrated latex}}{\text{Weight of field latex}}$$

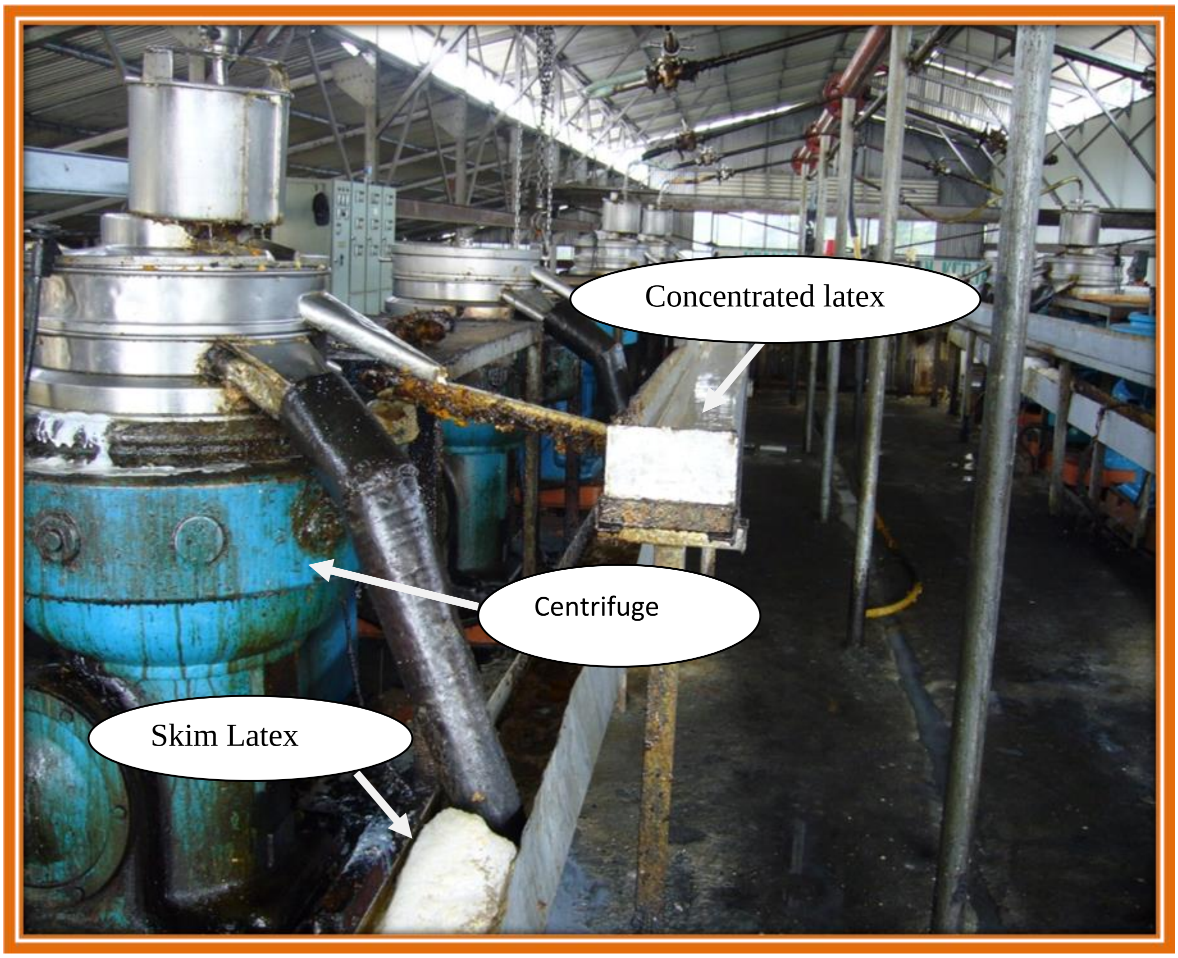

Figure 4.2: Centrifugation process where the light dense stream is concentrated latex and heavy dense stream is skim latex
Source: *Factory A, 2008*

v. Weight Tank B

From the centrifuge concentrated latex is poured into the Weight Tank B. Chemicals are added to the weight tank, depending on the product requirement.

Latex concentrate from Weight Tank B will be analyzed to determine the quality of concentrated latex, as shown in Table 4.4.

Table 4.4: Specification of concentrated latex in Weight Tank B

Parameter	Productions of Latex Concentrate		
	Rubber Glove	Rubber Thread	Rubber for export
NH_3	7 g/L latex	4.5 g/L latex	7-7,5 g/L HA 2,5-2,7 g/L LA
TSC	Maximum 61.30%	Maximum 61.30%	Maximum 61.30%
DRC	60-60.20%	60-60.20%	60-60,20%
VFA	0.020	0.020	0.020 (HA)
KOH	Maximum 0.60	Maximum 0.60	Maximum 0.60
pH	10.30	10.30	10

Source: *Factory A, 2008*

vi. Mixing Tank

From Weight Tank B, latex concentrate flows into a Mixing Tank (MT), where 1.75ml - 2.0ml ammonium laurate is added per liter concentrated latex. The analysis of concentrated latex is as shown in Table 4.5.

Table 4.5: Specification of concentrated latex in Mixing Tank

Parameter	Concentrated latex			
	High Ammonia		Low Ammonia	
	60 %	60,5%	60 %	60,5%
NH_3	7-7.5 g/L latex	7.3-7.5 g/L latex	2.5-2.7 g/L latex	2.5-2.7 g/L latex
TSC	Max.1.8%>DRC	Max.1.8%>DRC	Max.1.8%>DRC	Max.1.8%>DRC
DRC	60-60.20	60.5 – 60.6	60-60.20	60.5 – 60.6
VFA	$\leq$ 0.020	$\leq$ 0.020	$\leq$ 0.018	$\leq$ 0.018

Source: *Factory A, 2008*

vii. Storage Tank

Concentrated latex which has met the quality requirements of NH_3, DRC, VFA, and TSC will be kept in the storage tank (Figure 4.3), for 7-10 days before being sold. The retention time of 7 to 10 days is necessary to increase the property of Mechanical Stability Time (MST) to about 600 seconds.

Concentrated latex in the storage tank is stirred for 15 minutes everyday to homogenize the contents.

Figure 4.3: Storage tank for concentrated latex

Source: *Factory A, 2008*

4.3.1.2 Block Skim Rubber (BSR) Processing

i. Coagulation pond

Skim latex from the centrifuge is flowed into deammoniation tower in order to reduce ammonia content. From deammoniation tower skim latex flows through Fan Basin and is fanned for about 10 hours in order to reduce ammonia content until it reaches $\leq$ 1.10 g/L and flows into coagulation pond (Figure 4.4). According to Jawjit et.al., (2013) deammonization is done in order to reduce the amount of acid used for coagulation. In the coagulation pond, the skim latex will coagulate to form coagulum by adding 6 L formic acid (90%) per ton skim latex. Coagulation is completed after 2-3 days.

The quantity of acid as coagulant depends on various factors such as the amount and type of anticoagulant, duration of coagulation and the season. Coagulum from latex often shows a tendency for surface darkening. To prevent this, a small quantity of sodium bisulphite (1.2 g per kg DRC), dissolved in water may be added to the diluted latex before coagulation (RBI, 2006).

Figure 4.4: Coagulation pond

Source: *Factory A, 2008*

ii. Macerator

Coagulum (clot) from coagulation basin is taken out from the basin and sent to an area where the coagulum is cut into smaller pieces (30x30x10 cm^3) as shown in Figure 4.5. These coagulums together with the cup lumps taken from the plantation are milled to form thin layer rubber sheets using a macerator reducer as shown in Figure 4.6. It was observed that no waste and water loss are produced from this stage, but energy is used to operate the macerator.

Figure 4.5: Pieces coagulum after size reduction
Source: *Factory A, 2008*

Figure 4.6: Macerator

Source: *Factory A, 2008*

iii. Creper

Sheets from the macerator reducer then enter a wash basin to separate acids, dirt such as bits of wood and sand which are still attached to the sheets. Water in the wash basin is replaced periodically. Acid content is not measured, so the water in the wash basin would be replaced based on the experience of the workers through visual observation. The sheets are lifted onto a conveyor, then milling is continued in Creper I to reach (3 x 3 x 0.5) cm^3 thickness. Milling is further continued in Creper II to produce sheets of (2 x 2 x 0.5) cm^3 thickness. It is observed that no waste is generated in this unit, energy is used to operate creper and there are no water losses.

iv. Hammer Mill

The sheets from the creper then goes into the hammer mill where the sheets are further cut resulting in crumbs of 0.3-0.4 cm thickness. It is found that no waste is generated in this unit, energy is used to drive hammer mill motor and there is no water loss.

A set of cutters for size reduction from sheet into crumbs is shown in Figure 4.7.

Figure 4.7: A set of cutters for size reduction from sheet into crumbs
Source: *Factory A, 2008*

v. Dryer

The crumbs which have been cut to 0.3 -0.4cm sizes are inserted into boxes where each box weighs about 35 kg of crumb rubber. The boxes are conveyed to a dryer (Figure 4.8) operating at 115^{0}C - 120^{0}C for 3-3.5 hours.

Figure 4.8: Set of dryer

Source: *Factory A, 2008*

vi. Cooling

After drying the crumb rubber from the dryer is cooled by using cooling fan and blower until a temperature of 40 ^{0}C is reached. Cooling the crumb rubber is achieved within 30-40 minutes.

vii. Pressing

After the cooling stage, the 35 kg crumb rubber is pressed into block skim rubber and wrapped in a plastic measuring 70 cm x 35 cm x 20 cm in size per package (Figure 4.9).

Figure 4.9: Pressing and block skim rubber after packaging
Source: *Factory A, 2008*

4.3.2 Processing in Factory B

The trade name of concentrated latex in the Factory B is CENEX^{TM} (Centrifuged Latex) which indicates that the concentration process uses centrifugation. Initially, Factory B produces high ammonia latex concentrate (HA)-type NC 405, low ammonia (LA)-type NC 411 and NC 407 (very LA), but since 2000 only HA latex concentrate with fixed specification as stated in Table 4.2 is produced. This is because it is very difficult to maintain LA latex concentrate.

The products in Factory B can be classified as concentrated latex and solid rubber. Liquid latex is used as raw material for centrifugation and solid rubber is compressed in cup lump and is used as raw material in the Skim Rubber Plant. The flow process of natural rubber latex concentrate for Factory B is as shown in Figure 4.10.

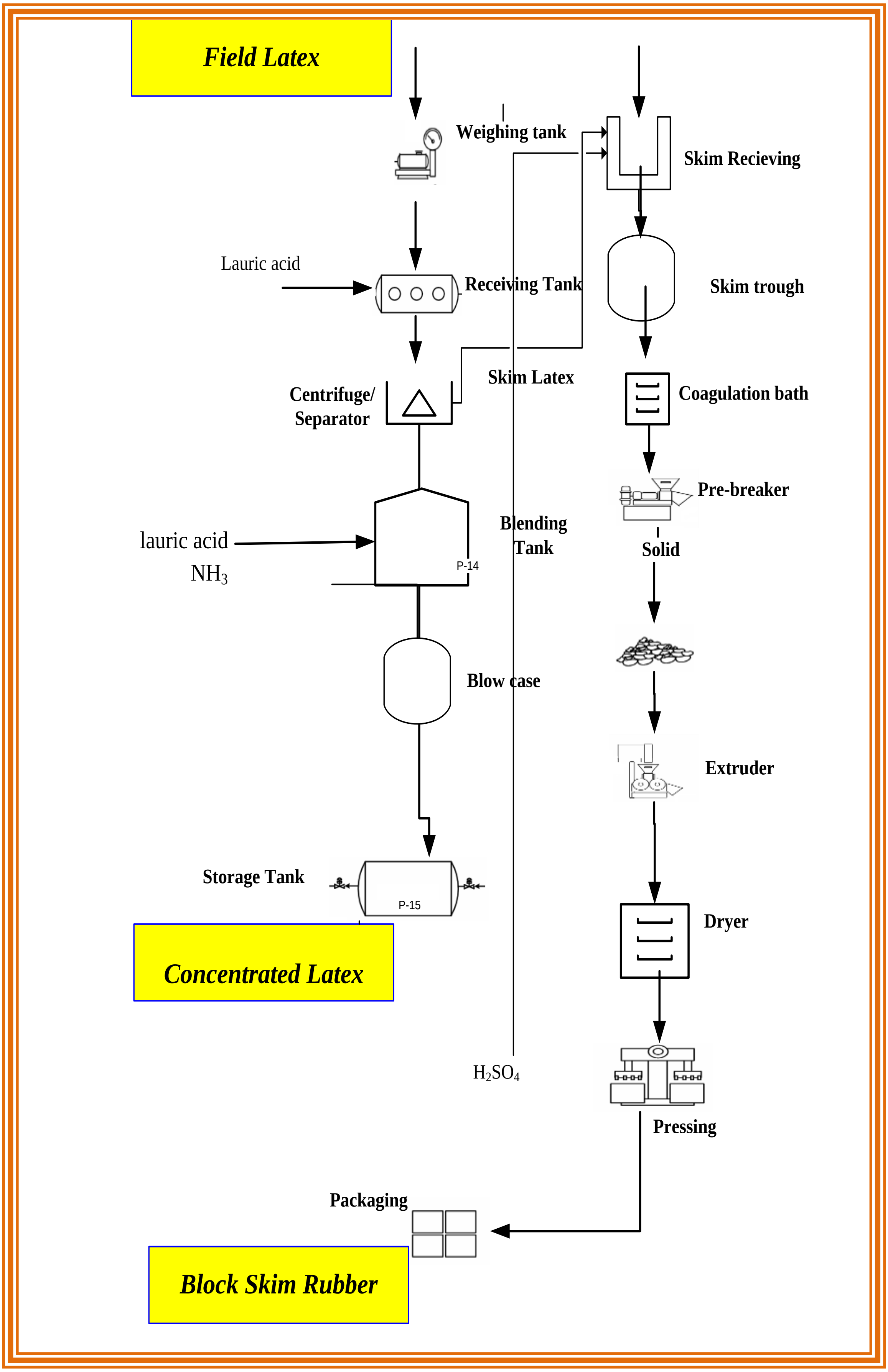

Figure 4.10: Flow Diagram Natural Rubber Latex Concentrate Processing in Factory B

Source: *Factory B, 2008*

4.3.2.1 Latex Concentrate Processing

Field latex is collected in the receiving tank. Retention time in the receiving tank is 2 hours after which the latex flows through a separator for centrifuging. Each centrifuge can process up to 300-320 kg latex per hour, rotating at 6,500 rpm and serves to separate rubber from non-rubber materials using centrifugal force.

The fraction of rubber that has been concentrated is formed as top layer in the separator bowl and flowed into a funnel and poured into a blending tank. This latex is then poured into a blow case and stored for approximately 8 hours and tested for consistency before finally being sent to storage tanks.

i. Weight Tank

The field latex from plantation is weighed in the factory. Upon an arrival at the factory, each truck which delivers field latex will be weighed using a weighing-bridge. After that the latex is sent to the Receiving Tank.

ii. Receiving Tank

In the receiving tank as shown in Figure 4.11, lauric acid is added to latex at 0.5 ml per kg of field latex. Latex is stored in the receiving tank for about 2 hours. After 2 hours, latex is flowed to the Ccntrifuge. System boundary for the factory starts from Receiving Tank.

Figure 4.11: Receiving Tank

Source: *Factory B, 2008*

iii. Centrifuge

The centrifuge (Figure 4.12) acts as a separator to separate rubber and non-rubber in field latex by using centrifugal force. Bowls in centrifuge rotates at a high speed of 6,500 rpm. The fraction of rubber which has been formed is known as the concentrated latex (Cenex^{TM}) with 63% DRC. Concentrated latex flows to the upper layer in the separator and will flow into the funnel and directed streams towards blending tank. The skim fraction in the bottom layer with dry rubber content 7% will flow into another funnel directed streams toward a skim latex receiver. A skim screw in the centrifuge served to set dry rubber content in concentrated latex. Short skim screw would yield higher dry rubber content and vice versa. Centrifuge is cleaned after each operation.

Figure 4.12: Centrifuge in Factory B

Source: *Factory B, 2008*

iv. Blending Tank

In the blending tanks (Figure 4.13), 2 ml lauric acid (10%) is added per kg of concentrated latex and the addition of ammonia ranged between 0.70-0.84% of the total weight depending on the needs of the end product. From the blending tank, concentrated latex flows to a blow case.

Figure 4.13: Blending Tank in Factory B
Source: *Factory B, 2008*

v. Blow Case

The concentrated latex from blending tank flows into a blow case (Figure 4.14) and is stored for 8 hours. The 8 hours storage is necessary to obtain the latex concentrate with the desired consistency. Following this stage latex concentrate is sent to storage tanks (Figure 4.15).

Figure 4.14: Blow case

Source: *Factory B, 2008*

Figure 4.15: Storage Tanks

Source: *Factory B, 2008*

4.3.2.2 Block Skim Rubber (BSR) Processing

Skim latex from the centrifuge has high ammonia content, therefore ammonia content has to be reduced by vaporizing the ammonia in a deammoniation tower. From the deamoniation tower the skim latex goes through a coagulation bath. A lower content of ammonia makes the rubber easier to freeze and also makes the usage of H_2SO_4 more efficient.

Skim latex stays in the Skim Latex Receiver as coagulation bath (Figure 4.16) for 2 to 3 days to form coagulum where simultaneously coagulant one liter of H_2SO_4 (10%) is added per 50 kg skim latex. In Factory B source of block skim rubber (BSR) comes from skim latex, rubber from washing equipment and cup lumps from plantation.

Figure 4.16: Skim Latex Receiver
Source: *Factory B, 2008*

i. Pre-breaker

The coagulum is removed from the bath and enters a pre breaker machine (Figure 4.17), where the coagulum is cut into thin layer crumbs of 7-7cm size with thin layer. The crumbs are then washed in a circulation bath to remove impurities such as sand, and excess acid which is still attached in the crumbs. After washing in the circulation bath, the crumbs are lifted up by a bucket elevator and put into an extruder machine (Figure 4.18). There are no crumb losses and energy is used to operate the pre-breaker.

Figure 4.17: Pre Breaker Machine
Source: *Factory B, 2008*

ii. Extruder

From circulation bath crumbs are transferred by bucket elevator to Extruder. The function of the extruder is to minimize the crumbs to 3.5-7mm size. By using bucket elevator the crumbs are transferred to circulation bath and washed. After washing, the crumbs is placed on the pan by using static screen pump.

Figure 4.18: Extruder

Source: *Factory B, 2008*

iii. Drying Machine (Dryer)

Drying machine is used to dry the crumbs by vaporizing the water content, in order to prevent growth of fungi and microbes. The crumbs which still contains about 15-20% water in the pan is placed in dryer (Figure 4.19). The dryer is equipped with burners and an air blower to blow the hot air from the burners to the pan that contain crumb rubber. Circulation of hot air through the crumbs cause water to evaporate. The first burner is usually set at a temperature of 105-110 °C and a second burner at a temperature of 110-125 °C and drying is conducted for 3.5 hours.

Figure 4.19: Drying Machine (Dryer)
Source: *Factory B, 2008*

iv. Cooling

The crumbs in the pan from the dryer is cooled by using a cooling fan and blower until the temperature is brought down to 40 ^{0}C within 30-40 minutes.

v. Pressing

After cooling the crumb rubber is weighted into bales of 35 kg each and sent to the ball press for packaging in plastic. Each bale measures 70 cm x 30 cm x 10 cm in size. Each bales is packaged with plastic polyethylene, where melting point of the plastic is 108 ^{0}C.

4.3.3 Comparison of process activities between Factory A and Factory B

The main equipment for concentrating latex in both factories is the centrifuge which acts as the separator for producing concentrated latex as the main product and skim latex as a side stream. Further processing of skim latex is necessary to produce block skim rubber as by product. Factory A has a sedimentation tank before the centrifuge where Diammonium Phosphate (DAP) is added to the latex in sedimentation tank. Adding of diammonium phosphate will bind Ca^{2+} and Mg^{2+} in the presence of NH^{+} ion and phosphate ion PO_4^{3-} to form complex compounds that can precipitate as Ca^{2+} and Mg^{2+}. However, Factory B adds diammonium phosphate to the fresh latex in the field to allow for longer reaction time.

After centrifugation, Factory A uses a mixer to mix the chemicals such as ammonia, ammonium laurate and diammonium phosphate before being stored in a storage tank. However Factory B uses a blending tank where chemicals are added before entering a blow case. A blow case is used to ensure the desired consistency by storing the latex for about 8 hours. Chemicals used for the latex concentrate processing by both factories are different except for ammonia which is used as an anti coagulant by both factories.

In the block skim rubber processing, Factory A employs different stages and with more equipments compared to Factory B. Among the differences are, Factory A uses a macerator which serves to cut coagulum and cup lump into smaller pieces, followed by cutting tools, namely creper 1, creper 2 and hammer mill. Factory B uses cutting tools such as, pre-breaker and extruder. Other equipments for drying and pressing unit are similar. During block skim rubber processing, Factory A produces sheets of solid rubber in the macerator before chopping, while Factory B chops solid rubber directly in pre breaker.

4.4 Inventory Data Collection

The trend of rubber balance, energy consumption and water consumption is captured based on field observations for different capacity processing of latex concentrate and block skim rubber. This similarity can be explained by the fact that the factory used similar technologies and production processes. The data in this study have been observed under various conditions of processing field latex. Three different capacities of processing field latex (high, low and medium) were selected and the average value was used as basis of calculation.

Data collection are divided into four parts: material which includes rubber balance and chemical consumption, energy, water and residue.

4.4.1 Material Data

The materials that are selected in this process are identified as rubber and chemicals. The rubber is measured in terms of dry rubber content. The data were taken for production capacity in three consecutive months (August, September, October) in the year 2008, in order to minimize variations.

4.4.1.1 Rubber balance

Freshly tapped field latex is in sterile condition, but upon exposure to air, field latex can be contaminated or damaged through several mechanisms. Damage to field latex, among others, can be caused by microorganisms from the air, cleanliness of equipment and rainwater. Microorganisms will grow rapidly in the field latex and break the proteins and carbohydrates into short-chain volatile fatty acids. At pH 4 to 5 the field latex reaches iso-electric point which leads to coagulation. Very moist conditions favor growth of microorganisms, so the surrounding areas need to be kept clean to reduce humidity.

The overall rubber balance is shown as in Figure 4.20. Data are collected directly from the factories in three sets at different capacities. Average values were calculated as shown in Tables 4.6 and 4.7 to formulate life cycle inventory.

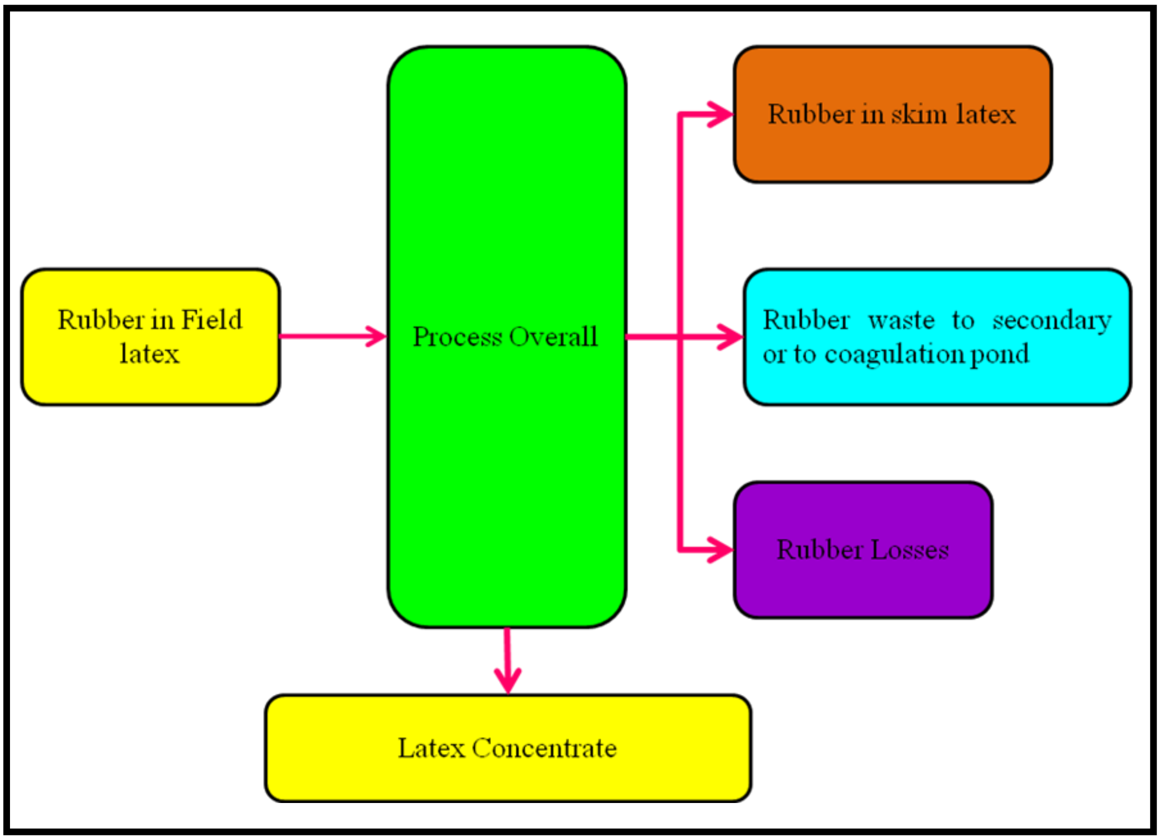

Figure 4.20: Overall rubber balance in Natural Rubber Latex Concentrate Processing

Table 4.6: Rubber balance in Natural Rubber Latex Concentrate Processing for Factory A

No	Rubber	Weight 1st month (kg)	Weight 2nd month (kg)	Weight 3rd month (kg)	Average Rate (kg/month)
1	Field Latex	2,220,555	2,254,322	1,874,635	2,116,504
2	Rubber in field latex	643,960	655,106	544,768	614,611.33
3	Rubber in latex concentrate (main product)	569,004	576,690	479,887	541,860.30
4	Rubber in skim latex (by product)	42,823	45,726	37,698	42,082
5	Rubber losses	6,375	6,485	5,393	6,084.33
6	Rubber to secondary pond	25,758	26,205	21,790	24,584.33

The difference between maximum and minimum capacity rubber production is 16% for Factory A. It appears that DRC is not markedly different as it ranged between 29%-29.06% DRC of field latex, 88.03%-88.36% DRC for concentrated latex, 6.65 %-6.98% DRC for skim latex, rubber losses about 0.99% and 4% DRC in the secondary pond. The trend in composition of rubber (DRC) shows good consistency in the quality of raw materials, equipment, and chemical use.

Table 4.7: Rubber balance in Natural Rubber Latex Concentrate Processing for Factory B

No	Rubber	Weight 1^{st} month (kg)	Weight 2^{nd} month (kg)	Weight 3^{rd} month (kg)	Average Rate (kg/month)
1	Field latex	3,274,230	2,406,910	2,846,127	2,842,422
2	Rubber in field latex	1,058,646	747,677	923,688	910,004
3	Rubber in latex concentrate (main product)	951,824	670,496	829,637	817,319
4	Rubber in skim latex (by product)	72,517	49,357	65,763	62,546
5	Rubber losses	10,390	7,100	6,450	7,980
6	Rubber to coagulation bath	23,915	20,724	21,838	22,159

The difference between maximum and minimum of field latex capacity is 26.5% for Factory B. The values for DRC varies from 31.06% - 32.45% in field latex, by 89.68% - 89.91% in concentrated latex, 6.60% - 7.12% in skim latex, 0.70%-0.98% DRC losses, 2.26%-2.77% in coagulation bath. It can be observed that an average the range of variability of DRC from various process is small i.e. <1%.

The trend of composition of rubber (DRC) in Factory B is similar Factory A and there is a good consistency in quality of raw materials, equipment, and chemical use.

From the above information, it can be concluded that the composition of dry rubber content is similar for Factory A and Factory B.

Factory B has higher DRC in field latex of about 32% whereas in Factory A, DRC was about 29%. Anas, (2007), reported that the chemical properties of field latex can be influenced by several factors such as types of clones, age of plant, tapping system and climate.

It was reported at the National Workshop on Rubber Plant Breeding that the latest rubber plants recommended for superior clones are from IRR series, IRR 5, IRR 32, IRR 39, IRR 42, IRR 104, IRR 112 and IRR 118 (BF, 2012), (Hartoyo, 2013). Field latex is very **s**usceptible to destabilization caused by the presence of bacteria from the air, yeast and molds in dust. Cleanliness is required during tapping because the entry of these microorganisms caused the proteins to change into acids which will coagulated the latex (Cecil, 2003) So cleanliness in tapping system greatly affects the quality of field latex.

4.4.1.2 Chemical consumption

There are differences in the chemical consumption used at both plants, as shown in Table 4.8. Factory A uses diammonium phosphate to remove Mg and Ca compounds within the factory premise while Factory B add diammonium phosphate in the field to enable more Ca and Mg substances to precipitate. Factory A uses a weak acid (formic acid) for coagulating skim latex which requires longer time than Factory B which uses a stronger acid (sulfuric acid).

Table 4.8: Chemical consumption for Factory A and Factory B

No	Chemical	Factory A	Factory B
	LATEX CONCENTRATE		
1	Ammonia	28 g/ L field latex	0.8% on ton weight of field latex
2	TZ 25%	1.5 ml/L conc. latex	500g/ ton conc. latex
3	Di-ammonium phosphate (DAP)	1.5 ml/ L conc. latex	-
4	Ammonium laurate	2 ml/ L conc. latex	-
5	Lauric Acid	-	2 ml/ kg conc. Latex
	BLOCK SKIM RUBBER		
1	Formic acid	6 L/ 1,000 kg skim latex	
2	Sulphuric Acid		20 L/ 1,000 kg skim latex

Source: Factory A and Factory B, 2008

i. Ammonia

Ammonia is added to field latex to prevent and to slow down microbial growth. Microbes are able to convert protein and carbohydrate in rubber into volatile fatty acids. If pH of the field latex decreases to 4.5-5.5 and reach its iso-electric point, rubber will coagulate. Ammonia and water will react in the following manner (Eq. 4.1)

$$NH_3+H_2O \leftrightharpoons NH_4^{+}+OH^{-} \qquad \text{……..} \quad \text{(Eq. 4.1)}$$

OH^- ions will neutralize the fatty acids which are formed by microbial activity.

At Factory A, ammonia is added in several stages to Onvangen Tank, Weight Tank A, Weight Tank B and Mixing Tank with the total amount of 28g/ L field latex. Addition of ammonia at Factory B is 0.8% of total weight of field latex andis added to Blending Tank.

ii. Tetra Methyl Thiuram Disulphide (TMTD) and Zinc Oxide (ZnO), TZ 25%

TZ 25% dispersion is a preservative containing Zinc Oxide (ZnO) as activator and Tetra Methyl Thiuram Disulphide ($[(CH_3)_2NCS_2-]_2$) which serves as a vulcanizing accelerator. Normal usage of TZ is as anti fungicide. TZ 25% mixture contains equal percentages (12.5%) of tetra methyl thiuram disulphide and zinc oxide in water. Fraction of NaOH and dispersing material are also found in this mixture, which acts as a primary and a secondary accelerator or sulfur as donor (vulcanizing agent) in most sulfur-cured elastomers in the rubber industry. In Factory A, TZ is added to the Weight Tank A and Weight Tank B at about 1.5 ml per L concentrated latex. In Factory B the addition of 500 g TZ per ton concentrated latex takes place in Receiving Tank.

iii. Diammonium phosphate (DAP)

Diammonium phosphate (DAP) is used to enable ammonia NH^+ ions to bind Ca^{2+} and Mg^{2+} and form complex compounds that precipitate (Anas, 2007), following the reaction:

$$Mg^{+2} + NH_4^{+} + PO_4^{-3} \longrightarrow MgNH_4PO_4 \qquad \text{(Eq. 4.2)}$$

Factory A adds DAP in Onvangen Tank and Mixing Tank with total amount of 1.5 ml/ L concentrated latex, while Factory B adds DAP in the field.

Magnesium is removed from the latex before or during centrifugation to ensure high quality of latex concentrate, by the addition of diammonium phosphate (DAP) to the field latex. The exact amount of the salt should be used. Too much addition of DAP can cause reduction of the mechanical stability of products, while too little DAP can cause the undesirable reactions mentioned above to occur (Cecil, 2003).

iv. Lauric acid

Lauric acid in ammonia will react to produce ammonium laurate, as in the following reaction:

$$CH_{11}H_{23}COOH + NH_4OH \longrightarrow CH_{11}H_{23}C\begin{matrix} {}^{\diagup\!\!\diagup O} \\ {}_{\diagdown ONH_4} \end{matrix} + H_2O \qquad (4.3)$$

In the receiving tank, 2 ml lauric acid (10%) is added per kg field latex. Besides stabilizing the field latex, lauric acid also act to optimize the separation process between the rubber and skim fraction when the field latex is processed in the centrifuge.

4.4.2 Energy Consumption

Energy usage in a manufacturing environment relates to the use of mechanical devices such as motor and latent heat may be necessary as in drying process. Normally, phase change operation requires more energy than simple frictional losses in mechanical devices. Motors, heaters and cooling system are the main electrical energy users in rubber processing and motors use approximately two-thirds of the energy costs in rubber processing (Technology, 2009).

Energy consumption for latex concentrate and block rubber processing for each factory are shown in Table 4.9 and Table 4.10.

Table 4.9: Energy consumption Natural Rubber Latex Concentrate Processing for Factory A

Energy	Energy 1st month (kWh)	Energy 2nd month (kWh)	Energy 3rd month (kWh)	Average Energy (kWh/month)
Energy for Latex Concentrate (kWh)	**76,227**	**81,707**	**74,165**	**77,366.33**
Latex Concentrate (kg)	569,004	576,690	479,887	541,860.3
Energy for Block Skim Rubber (kWh)	**6,150**	**6,032**	**4,325**	**5,502.33**
Block Skim Rubber (kg)	30,760	30,170	21,630	27,520
Total Energy (kWh)	**82,377**	**87,739**	**78,480**	**82,865.33**

Increased production capacity of latex concentrate in Factory A from 479,887 kg to 576,690 kg, a simultan linear increase of energy use from 74,165 kWh to 81,707 kWh (Table 4.7). Energy consumption of latex concentrate processing for Factory A varies between 13.40% to 15.45% based on latex concentrate production capacity for each month. The trend of energy consumption was not much different, showing the equipment used still have the same ability.

Similarly, the increase in the production of block skim rubber, also means the increase of energy usage. To process block skim rubber of Factory A, the amount of energy consumption is 20% of production capacity of block skim rubber for each month.

The trend of linear increase in energy use for latex concentrate production and block skim rubber showed that the quality of field latex meet the requirement standards that have been set. Besides, the equipment used still has the same efficiency at each processing.

Table 4.10: Energy consumption Natural Rubber Latex Concentrate Processing for Factory B

Energy	**1st month (kWh)**	**2nd month (kWh)**	**3rd month (kWh)**	**Average (kWh/month)**
Energy for Latex Concentrate (kWh)	**94,114**	**65,648**	**75,118**	**78,293.33**
Latex Concentrate (kg)	951,824	670,496	829,637	817,319
Energy for Block Skim Rubber (kWh)	**43,560**	**30,084**	**47,748**	**40,464**
Block Skim Rubber (kg)	358,024	249,467	340.683	316,058
Total Energy	**139,674**	**97,732**	**124,866**	**118,757.33**

Energy consumption of latex concentrate processing for Factory B varies between 9.05% to 9.89% based on latex concentrate production capacity for each month. To process block skim rubber of Factory B, the amount of energy consumption varies from 12.06% to 14.02% of production capacity of block skim rubber each month.

The trend of energy consumption in natural rubber latex concentrate processing of Factory A and Factory B is not much different. This similarity can be explained that both factories are using the same technology, process production and the equipments still have the same ability.

4.4.3 Water Consumption

Water is used for washing the equipment during batch processing of latex concentrate, and washing of centrifuge has the highest water consumption. Every two hours centrifuge should be washed to prevent the buildup of solids that can interfere with rotation of centrifuge.

Block skim rubber processing uses water to wash the coagulum from coagulation pond and cup lumps from plantation. In addition, washing is continued during rubber sheet processing.

Water consumption data for Factory A and Factory B are given in Table 4.11 and Table 4.12 respectively.

Table 4.11: Water consumption in Natural Rubber Latex Concentrate Processing for Factory A

Water Consumption	1st month (m^3)	2nd month (m^3)	3rd month (m^3)	Average (m^3/month)
1. For Latex Concentrate (m^3)	**10,613**	**10,115**	**10,755**	**10,494**
Latex Concentrate (kg)	569,004	576,690	479,887	541,860
2. For Block Skim Rubber (m^3)	**1,075**	**1,054**	**755**	**961**
Block Skim Rubber (kg)	30,760	30,170	21,630	27,520
Total (m^3)	**11,688**	**11,169**	**11,510**	**11,455**

Data for water consumption for Factory A show that increase in production capacity of concentrated latex from 479,887 kg to 576,690 kg, did not result in linear increase in water consumption. Water consumption of latex concentrate processing for Factory A varies between 1.75% to 2.24% of latex concentrate production capacity for each month. The utilization of water for washing equipment is done manually and the cleanliness of equipments is assessed visually, therefore water consumption is not controlled. Consequently this situation will create an impact on eco-efficiency.

Meanwhile, water consumption in block skim rubber on Factory A shows consistency of 3.49% for various block skim rubber processing capacity. It shows that coagulum and cup lumps as raw materials are consistent in characteristic.

Table 4.12: Water consumption Natural Rubber Latex Concentrate Processing for Factory B

Water Consumption	**1st month (m^3)**	**2nd month (m^3)**	**3rd month (m^3)**	**Average (m^3/month)**
Water for Latex Concentrate (m^3)	**11,426**	**8,303**	**8,132**	**9,287**
Latex Concentrate (kg)	951,824	670,596	829,637	817,319
Water for Block Skim Rubber (m^3)	**3,518**	**2,570**	**4,332**	**3,470**
Block Skim Rubber (kg)	358,024	249,467	340,683	316,058
Total (m^3)	**14,944**	**10,873**	**12,464**	**12,760**

Processing capacity for Factory B, latex concentrate of 670,596 kg utilize 8,303 m^3 water, while latex concentrate capacity processing of 829,637 kg consume 8,132 m^3 water. This situation may arise due to manual washing of equipment, and the cleanliness of equipments is only based on visually inspection. As a result water consumption is not well controlled. Water consumption in latex concentrate processing is in the range of 0.98% to 1.24% per kg latex concentrate production. In consequence this situation will generate an impact on eco-efficiency.

Meanwhile, water consumption for block skim rubber processing of Factory B is in the ranged from 0.98% to 1.27% per kg block skim rubber production. It demonstrates consistency of water utilization in block skim rubber processing.

4.4.4 Residuals

The processing of natural rubber latex also produces some residues in term of emission to the air as air emission, discharge to water as wastewater and losses (solid) in term of wastes generation. In latex concentrate processing these residuals are in the form of gasses through direct emission from the chimney, 1% of solid wastes appear in the form of coagulated rubber and wastewater from washing the equipments. In the block skim rubber processing, the residuals appear in the form of wastewater produced during washing of the coagulum and cup lump. Solid losses are negligible.

4.4.4.1 Air Emission

In rubber processing, a furnace is used to produce heat by burning fuel, normally releases smoke through a chimney. Smoke darker than a specified shade of grey is officially classified as 'dark smoke' and is deemed as pollution. In order to prevent smoke, dust, and fume emissions from damaging human health or causing nuisance, the design of the chimney must comply with the relevant regulation of Indonesia.

Based on N0: Kep -205/ Bapedal/07/1996 requirement, the height of the chimney should be 2 - 2.5 times higher than the height of surrounding buildings, to ensure good dispersal of the effluent released through the chimney (BAPEDAL, 1996). Emission parameters should adhere to the Regulation of the Ministry of Environment Republic of Indonesia Kep-13/MENLH/3/1995 on standards of quality for air emission from stationary source (KLH, 1995b).

The average concentration of the air emission parameters is obtained from measurements of air emission. The fuel used in the furnace is diesel fuel which consist of carbon and other elements such as: sulfur , Nitrogen. During combustion SO_x and NO_x will be produced. Particulate is solid phase which is dispersed in the air due to incomplete combustion.

In this study air emission parameters such SO_2, NO_2 and particulates were measured for Factory A (Table 4.13) and Factory B (Table 4.14).

Table 4.13: Air emission concentration in Factory A

No	Parameter	Concentration(mg/m^3)			Standard Requirement (mg/m^3)
		1	2	3	
1	**SO_2**	32.15	36.19	41.45	800
2	**NO_2**	14.45	4.18	52.4	1000
3	**Particulate**	90.17	104.14	185	350

Table 4.14: Air emission concentration in Factory B

No	Parameter	Concentration(mg/m^3)			Standard Requirement (mg/m^3)
		1	2	3	
1	**SO_2**	95.06	54.2	95	800
2	**NO_2**	105	90.09	105	1000
3	**Particulate**	63.52	50.3	90.28	350

Based on measurements of air emission quality for Factory A and Factory B, air emission concentration parameters for air comply with the applicable standard requirements.

4.4.4.2 Wastewater

Although a variety of NR based products have greatly contributed benefits for the development of mankind, the consequence of natural rubber processing has yet to provide sustainable solution arising from its highly contaminated effluents. The rapid growth of this industry generates large quantities of effluent coming from its processing operations which is really a significant problem. According to Ganeshan, (1995), skim, latex serum, uncoagulated latex and washings are the main sources of rubber wastewater in Malaysia. Without suitable handling, discharge of wastewater from rubber processing industry to the environment may cause crucial and long-term effect.

In Malaysia, regulatory requirements based on the Environmental Quality Act(1974), for rubber processing industry has been enforced since 1978 (Revision, 2006). Most rubber latex processing has a wastewater treatment plant. However more effort need to be done to recover valuable by-products in the residual especially wastewater.

Wastewater management technologies in natural rubber latex concentrate are continuously develop to meet changes in the quantity of the parameters that characterize the effluent and to comply with the increasingly stringent wastewater standard (Jayachandran, 1994), (Atagana, 1999), (Asia, 2007), (Mohammadi, 2010), (Danwanichakul, 2011), (John, 2011), (Nguyen, 2012), (Tamikawa et al., 2012).

Wastewater rubber processing parameters are characterized as nitrogen, sulfate, acidity shown as pH, biological oxygen demand (BOD), chemical oxygen demand (COD), suspended solid (SS). Wastewater characteristic in rubber industry depends on product (Van, 2007), (Mohammadi, 2010). A typical wastewater as a combined wastewater from rubber processing before treatment is as shown in Table 4.15.

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Table 4.15: Characteristic of combined wastewater before treatment

No.	Parameter	Value	Unit	Standard Requirement
1.	pH	6 -6.5		6-9
2.	BOD_5	1800 – 2400	mg/ L	100
3.	COD	3000 – 4000	mg/ L	250
4.	TSS	650 – 1,000	mg/ L	100
5	NH_3 Total	100 – 150	mg/ L	15
6.	N-Total	150 – 200	mg/ L	25

Source: Van *(2007)*

According to Nguyen and Luong (2012), wastewater from concentrated latex processing is more polluted compared to block rubber processing. It is because of the high concentration of un-coagulated particles and organic matters. Wastewater characteristic of skim latex processing is high in acid (Nguyen, 2012).

The high concentration of nitrogen contributes to undesirable eutrophication in rivers and stream and increases oxygen and chemical demand if the surface water is used as raw water feed for water supply. Sulfate comes from sulfuric acid which is used in the coagulation of skim latex, and will liberate H_2S to the environment which causes malodor problems. The free H_2S also inhibits the digestion process, which gives lower organics removal efficiency. The odors are detectable even at extremely low concentrations making water unpalatable for several hundred miles downstream from the rubber processing factories (Rungruang, 2008). The quantity of acid used for coagulation, is generally found to be higher than the actual requirement. The incomplete coagulation results in the loss of rubber particles into the effluent. The excess acid not only causes acidic effluent but also re-dissolves the rubber protein and causes delay in coagulation. Hence, it is suggested that proper acid concentration be applied and sufficient coagulation time should be identified to obtain optimum clear liquid after complete coagulation (Van, 2007). Deammoniation is carried out before coagulation and helps to reduce acid consumption. Danwanichakul et al., (2011) found that chitosan in polyacrylamide solution can separate 80% of the solid rubber in skim latex and quality of serum such as BOD, COD and pH become better than chitosan in sulfuric acid solution.

Reducing COD in wastewater has been investigated by Jayachandran (1994), using Acinetobacter sp. COD levels could be reduced by 39.5% from the previous COD of 22,000 mg/L.

Biological coagulation can be performed by using yeast which produced alcohol. Fermentation alcohol will coagulate the latex by removing water around the protein, thereby decreasing normal value hydration of the protein layer around the rubber particle. In that way the latex will destabilize and coagulation takes place. Coagulation in this way will not produce acid in the effluent (John, 2011).

Wastewater monitoring is carried out once a month for both factories based on cost consideration. For the functional unit, the wastewater is divided directly with the amount of production latex concentrate, since the wastewater data is not available on a daily basis. Wastewater volume is assumed similar to water consumption in latex concentrate processing and block skim rubber processing. Standard requirement for wastewater quality must comply with government regulation: Regulation of the Ministry of Environment Republic of Indonesia, Kep-51/MEN LH/10/1995, about Standard Requirement Wastewater for Rubber Industry.

Factory A measured pH, BOD, COD, TSS, NH_3 Total, N-Total (Table 4.16) as indicator parameter for rubber industry wastewater as required by Regulation of the Ministry of Environment Republic of Indonesia, Kep-51/MEN LH/10/1995.

Table 4.16: Wastewater discharge quality in Factory A before wastewater treatment

No.	Parameter	Outlet Monitoring				Unit	Standard Requirement
		1	2	3	Average		
1.	pH	7.3	7.5	7.23	7.34		6-9
2.	BOD_5	231	95.2	49.1	125.10	mg/ L	100
3.	COD	413	163	81	219.0	mg/ L	250
4.	TSS	140	264	75	159.67	mg/ L	100
5	NH_3 Total	34	100	4.8	46.27	mg/ L	15
6.	N-Total	104	121	9.25	78.08	mg/ L	25

Source: Factory A, 2008

Concentration of BOD and COD on the first outlet monitoring was above the standard requirement which means there is still a lot of organic and inorganic compounds in the wastewater effluent. In the third outlet monitoring from the whole of Factory A, all parameters are under the specified requirements. Total suspended solid in the first and second monitoring are above the required standard requirement, indicating that more rubber is carried to the effluent. It means that the effluent contains rubber that did not coagulate, as a result of the addition of too much acid which causes re-dissolution of protein, and coagulation will be disrupted. Re-dissolved protein causes high levels of nitrogen into the first and second outlet monitoring where the allowable requirement is 25 mg/L. Total ammonia in the second outlet monitoring exceeds the standard requirement which means the evaporation of ammonia on the de-ammoniation tower did not function as expected.

Based on first outlet monitoring of wastewater in Factory B, as shown in Table 4.17, COD, TSS and Total Nitrogen exceeded the values for allowable discharge requirement. The high value of COD was dominated by inorganic chemical, while organic compounds did not have an influence as BOD values are below the standard requirement. Total suspended solid is above the standard requirement, indicating that more rubber is carried in to the wastewater. Rubber in wastewater indicated that coagulation did not work properly as a result of too much acid addition which can cause re-dissolved protein, and therefore coagulation will be disrupted. Re-dissolved protein causes high levels of Nitrogen (121 mg/L), while standard discharge requirement allows only 25 mg/L.

Table 4.17: Wastewater discharge quality in Factory B before wastewater treatment

No.	Parameter	Outlet Measurement				Unit	Standard Requirement
		1	2	3	Average		
1.	pH	7.4	7.21	7.27	7.29		6-9
2.	BOD_5	28	38	48	38	mg/ L	100
3.	COD	622	110	133	288.33	mg/ L	250
4.	TSS	256	68	62	128.66	mg/ L	100
5	NH_3-Total	16	3.7	2.7	7.47	mg/ L	15
6.	N-Total	121	4.6	4.7	43.43	mg/ L	25

Source: Factory B

4.5 Life Cycle Inventory

The functional unit selected in this study is to produce 1 ton (1,000 kg) latex concentrate and 1 ton (1,000 kg) block skim rubber and all the information below are based on this functional unit.

4.5.1 Material

4.5.1.1 Rubber Balance

Latex as it appears from the tree regularly contains between 30-40% dry rubber content, the other 60-70% being mainly serum. Shipping this quantity adds greatly to costs, making exportation of ordinary latex uneconomic. Centrifugation is a simple way to concentrate suspensions in liquids and separate rubber to form latex concentrate and a by-product skim latex. Some rubber also makes its way to the coagulation pond and there are losses in rubber along the process lines (Cecil, 2003). Based on observations made by the DIW (2001) composition of rubber in concentrated latex varies from 79.1%-88.9%, in skim latex is 5.4%-14%, whereas losses is around 3%-8.9%.

Rubber to secondary pond in Factory A or rubber to coagulation pond in Factory B is derived from cleaning of machinery and is used for the manufacturing of block skim rubber. The composition of rubber balance from Factory A and Factory B are represented in Table 4.18 and Table 4.19 respectively. The value of rubber component are based on weight in kg and composition in percent.

Dry rubber content of latex concentrate from Factory A is 88.16% and 6.85% in the coagulation pond.

Table 4.18: Rubber balance of Factory A

	Component	**Rubber balance (kg)**	**Rubber Percentage**
INPUT	Field latex	3,906	
	Rubber in field latex	1,134	29.04
OUTPUT	Rubber in latex concentrate (main product)	1,000	88.16
	Rubber in skim latex (by product)	78	6.85
	Rubber losses	11	0.99
	Rubber to secondary pond	45	4

Dry rubber content of latex concentrate from Factory B is 89.81% and 6.75% in the coagulation pond.

Table 4.19: Rubber balance of Factory B

	Component	Rubber balance (kg)	Rubber Percentage
INPUT	Field Latex	3,501	
	Rubber in field latex	1,113	31.8
OUTPUT	Rubber in latex concentrate (main product)	1,000	89.81
	Rubber in skim latex (by product)	75	6.75
	Rubber losses	11	0.97
	Rubber to coagulation pond	27	2.47

A sample calculation of rubber balance from Factory A and Factory B is given in Appendix B.

The DRC in field latex of Factory A is slightly lower at 29.04% than Factory B where DRC is 31.80%. DRC differences between Factory A and Factory B are mainly due to the differences in process and chemical consumption as discussed in section 4.4.1.1. Rubber composition differences can also occur in field latex due to different clone of rubber trees and climate (Anas, 2007). The rubber composition in natural rubber latex concentrate processing for Factory A and Factory B are still within the range reported by the DIW (2001).

4.5.1.2 Chemical Consumption

Processing of natural rubber latex can have a variety of choices of chemicals to achieve the same function. According to Anas, (2007), the use of ammonia is 20-23 kg per ton of dry rubber and ammonium laurate is 1-1.2 kg per ton of dry rubber in concentrated latex processing. The DIW (2001) made observations on 11 industries and reported that, ammonia usage for these industries ranged from 12.2-25.3 kg/ ton of concentrated latex with an average of 21.1 kg/ ton of concentrated latex. Jawjit et al. (2012) observed that ammonia consumption average about 16-18 kg ammonia per ton of concentrated latex. Usage of TMTD and ZnO are equal at 0.5-0.7 kg per ton concentrated latex. DAP is added to remove magnesium and calcium compounds from fresh latex, and its consumption is about 2-2.5 kg per ton concentrated latex.

Chemical compounds which are used for both factories are shown in Table 4.20. Factory A uses 102 kg ammonia per ton of concentrated latex and Factory B uses 80 kg ammonia per ton of concentrated latex. Based on this information the use of ammonia in both factories are still very high compared to Jawjit's data. Jawjit et al (2012) reported 17 kg of ammonia is added per ton of concentrated latex. Factory A consumes 102.7 kg of ammonia per ton of concentrated latex, higher then Factory B which consumes 80 kg of ammonia per ton of concentrated latex. There are many aspects such as quality of field latex, which will consume more ammonia. Beside, the addition of ammonia is always based on routine practice without considering latex quality.

In the case of diammonium phosphate (DAP), Factory A adds DAP at the factory while Factory B adds DAP to the latex in the field. Factory A adds DAP twice, first in Onvangen Tank and second in Mixing Tank with the total amount of 5.28 L per ton of concentrated latex. Factory B adds DAP in the field where Ca and Mg compounds bind faster before being further processed in the factory . This is to ensure the latex becomes more stable. Sedimentation of calcium and magnesium ions is expected to ease the process of separation between concentrated latex and skim latex.

The addition of ammonium laurate is conducted differently in both factories, where Factory A adds 2.13 L ammonium laurate per ton of concentrated latex, while Factory B adds 2 L. lauric acid per ton of concentrated latex. Lauric acid is added to react with ammonia to form ammonium laurate. TZ which is a combination of tetramethylthiuram disulphide and ZnO, and its use in Factory A is a total of 1.12 kg per ton of concentrated latex and while Factory B uses 0.06 kg per ton of concentrated latex.

To produce block skim rubber, acids are added to skim latex to coagulate the rubber. Different compounds are used by the two factories. Factory A adds 7.33 kg of formic acid per ton of concentrated latex while Factory B uses sulfuric acid as much as 18.38 kg per ton of concentrated latex.

Table 4.20: Chemical consumption per ton of concentrated latex in Factory A and Factory B

No	Chemicals	Factory A	Factory B
LATEX CONCENTRATE			
1	Ammonia	102.7 kg	80 kg
2	TZ 25%,		
	ZnO = TMTD	1.12 kg	0.06 kg
3	Di-ammonium phosphate (DAP)	3.28 kg	-
4	Ammonium laurate	2.13 L	-
5	Lauric Acid	-	2 L
BLOCK SKIM RUBBER			
1	Formic Acid (90%)	7.33 kg	-
2	Sulfuric Acid (98%)	-	18.38 kg

4.5.2 Energy Consumption

Generally, energy consumption for a manufacturing entity is used in connection with mechanical devices such as motor and latent heat energy for phase changes such as in drying. Centrifuge is the major appliance which consumes energy in concentrated latex processing. Bowls in the centrifuge will rotate with a speed of approximately 6,000 rpm which causes the rubber particles to be thrown upward and serum moves downward. Meanwhile, in the processing of block skim rubber, dryer is the machinery used to dry the rubber and it consumes the most energy. Drying uses hot air at temperatures of 110-115 ^{0}C for 3.5 hours.

According to Anas (2007), electricity usage in latex concentrate processing is approximately 240 kWh per ton dry rubber or about or 151.2 kWh per ton concentrated latex, while for block skim rubber processing about 200 kWh per ton dry rubber. The DIW (2001) made observations on 10 industries and found the energy use ranges from 74.2 kWh to 241.9 kWh per ton of concentrated latex with an average of 90.0 kWh per ton of concentrated latex . Block skim rubber processing uses energy at 164 to 374 kWh /ton of dry rubber with an average of 200 kWh/ ton of dry rubber. Based on this information the use of energy for concentrated latex processing in Indonesia is still wasteful. However but for block skim rubber processing is still within the limits reported by the DIW. Jawjit et al (2012) noted that the average energy consumption in concentrated latex processing is about 105 kWh per ton concentrated latex and the centrifuge is the machine that consumes highest amount of electricity. Energy audit by Saidur and Mekhilef (2010) in Malaysia’s rubber and rubber industries showed electric motor as the equipment that consumes the highest energy followed by pumps and heaters.

Table 4.21 shows energy consumption in natural rubber latex concentrate processing for Factory A and Factory B. Energy consumption for block skim rubber processing is 40% greater than energy consumption for latex concentrate processing in Factory A. The composition of energy utilization is 0.58 for block skim rubber processing and 0.42 for concentrated latex processing for each functional unit in Factory A.

Energy uses in block skim rubber greater 34% than energy consumption in latex concentrate processing. in Factory B. The composition of energy use in Factory B is at 0.57 to block skim rubber processing and 0.43 for latex concentrate processing for each functional unit.

Table 4.21: Energy consumption of Factory A and Factory B

Component	Functional Unit	Energy Consumption (kWh)		Composition	
		Factory A	Factory B	Factory A	Factory B
Latex Concentrate	1000 kg	142.78	95.79	0.42	0.43
Block Skim Rubber	1000 kg	199.93	128.03	0.58	0.57

Table 4.19 shows that during latex concentrate processing Factory A is less efficient than Factory B since it uses 33% energy more. As for the block skim rubber Factory A uses 36% more energy than Factory B. The amount of additional energy required to process block skim rubber in Factory A compared to Factory B can be caused to use cup lumps. Lumps in Factory A which come from requirements independent sources, thereby cleanliness does not meet SNI 06-2047-2002. Lump in Factory B come from its own plantation therefore the quality and cleanliness can be regulated. Cup lump that come from other plantations still contain many pieces of wood and sand and must be washed repeatedly resulting in high energy and water usage (Utomo, 2010).

The amount of energy used in block skim rubber of Factory A and Factory B is still within the range of similar industry, although Factory A uses more energy than Factory B. Based on total energy usage in natural rubber latex concentrate, block skim rubber processing use energy more than concentrated latex processing for both factories.

Dryer, circulation fan and pressing are the equipments in block skim rubber processes that use the highest amount of energy.

The proper use of equipment and regular maintenance are important for consideration of energy savings. It takes approximately 15 minutes for the centrifuge to achieve the rotation of 6,000 rpm. Water is added to avoid friction between bowls and air in centrifuge which can cause the bowls become hot and causes high energy loss. The field latex will be conveyed to the centrifuge once the rotation is constant at 6,000 rpm,.

Energy consumption in natural rubber latex concentrate processing is used more for block skim rubber processing especially in the drying process. Energy consumption during drying involves sensible heat and latent heat for the phase change of water content to be evaporated. It means that water content before drying must be in a minimum amount to lower energy consumption.

4.5.3 Water Consumption

In the concentrated latex processing, water is used for cleaning machinery items, such as the centrifuge bowl. In block skim rubber processing, water is used for washing the acid from the coagulum and impurities such as sand, bits of wood from the cup lumps. According to Anas (2007), the use of water is approximately 25 m^3 per ton of dried rubber in concentrated latex processing, while for the block skim rubber processing is 30 m^3 per ton of dried rubber. According to observation by DIW (2001) on 11 industries, water consumption ranged from 1.8-15.8 m^3 per ton of concentrated latex with an average of 5.2 m^3 per ton of concentrated latex. For block skim rubber processing water consumption ranged from 6 - 56 m^3 per ton of dried rubber with an average of 23 m^3 per ton of dried rubber. Jawjit et al. (2012) observed that the average water consumption is about 6-7 m^3 per ton of concentrated latex.

Table 4.22 shows water consumption for natural rubber latex concentrate processing in Factory A and Factory B.

Table 4.22: Water consumption of Factory A and Factory B

Component	Functional Unit	Water Consumption (m^3)		Composition	
		Factory A	Factory B	Factory A	Factory B
Latex Concentrate	1000 kg	19.37	11.36	0.36	0.51
Block Skim Rubber	1000 kg	34.93	10.99	0.64	0.49

The data show that water use in Factory A is 19.37 m^3per ton of concentrated latex which is 44.5% less than water consumption for block skim rubber, which is 34.93 m^3 per ton of dried rubber. This is because Factory A uses lump from independent source which is low in cleanliness (Utomo, 2010). Therefore more water is needed in the block skim rubber processing.

Water used at Factory A in block skim rubber processing is more widely used for washing coagulum, and washing the cup lump from independent source and washing the thin layer of rubber at every stage before drying. Hence, cup lumps from independent sources need to obtain as clean cup lumps before it is sold to the factory.

Water consumption for Factory B as shown in Table 4.20 is 11.36 m^3/ton of concentrated latex and the amount is nearly the same for block skim rubber processing at 10.89 m^3/ton of concentrated latex.

It is necessary to consider the use of water for both processes. Factory A uses 70 % more water than Factory B for concentrated latex processing while water usage for block skim rubber in Factory A is 2.18 times more compared to Factory B. It shows that Factory B has already used the water efficiently.

Water consumption is closely related to the wastewater generated. The more water used, the more the amount of wastewater discharge (effluent) to a system (Leong S.T.; Muttamara S.; Laortanakul, 2003), (Rungruang, 2008). So water usage must be used efficiently.

4.5.4 Residuals

4.5.4.1 Air Emission

Diesel fuel is used in Natural Rubber Latex Concentrate processing. The use of diesel fuel generally is for all types of diesel engines with high rotation (above 1,000 RPM). Arismunandar (1983) said that the black smoke containing particulates are harmful exhaust gas components in diesel combustion. According to Nakula (1995), black smoke in chimney is caused by incomplete combustion due to lack of oxygen, or the amount of fuel is in excess. Under these conditions the carbon does not have enough time to diffuse with oxygen, resulting in carbon in the solid phase and becoming charred.

The average concentration of each parameter of air emission for Factory A and Factory B are shown in Table 4.23. Factory A consumed more energy then Factory B at 342.71 kWh per ton of concentrated latex which consumed total energy of 223.82 kWh per ton of concentrated latex. Total energy consumption influences the air emission concentration for particulate. In general, parameters of air emission for both factories are below the discharge limits according to Regulation of the Ministry of Environment Republic of Indonesia Kep-13/MENLH/3/1995 (KLH, 1995b).

Table 4.23: Air emission concentration in Factory A and Factory B

No	Parameter	Concentration (mg/m^3)		Standard Requirement (mg/m^3)
		Factory A	Factory B	
1	SO_2	36.6	81.4	800
2	NO_2	23.7	100.0	1,000
3	**Particulate**	126.4	68.0	350

4.5.4.2 Wastewater

Excessive water consumption will lead to high wastewater that will increase the burden on wastewater treatment system. Wastewater comes from coagulation pond and washing of coagulum before further process. Total Nitrogen is the sum of: the amount of N-organic + Total Ammonia + NO_2 + NO_3. Maximum load is defined as the amount of parameters in 1 ton of dry rubber and based on Regulation of the Ministry of Environment Republic of Indonesia, Kep-51/MEN LH/10/1995, for Standard Requirement for rubber industry wastewater.

Wastewater parameters of the two factories are measured and compared to maximum load that comply with requirement standard Regulation of the Ministry of Environment Republic of Indonesia, Kep-51/MEN LH/10/1995 (Table 4.24). Wastewater parameters of Factory A is higher than Factory B and some of the parameters e exceeds the standard requirement. Total weight of ammonia in wastewater amounted to 1.62 kg per ton of concentrated latex, almost 3 times the standard requirement. Excess of ammonia from concentrated latex processing will interfere in the coagulation process. Rubber in skim latex that has not coagulated will lead to high suspended solids. Total Suspended Solid (TSS) in Factory A was 5.6 kg per ton of concentrated latex, which is beyond the standard requirement. Atagana et al., (1999) conducted a study on treatment of wastewater from rubber processing, which comes from natural rubber waste serum and washing effluent by using fungi. He succeeded in reducing levels of BOD and suspended solid meaning it can also reduce levels of COD. Ponds with effective design and optimally operated can reduce over 95% biological oxygen demand (BOD) from rubber wastewater (Ahmad, 1983). Nguyen and Luong (2012) concluded that combining biological, physical and chemical treatment will provide high removal of pollutant in wastewater of natural rubber processing at effective cost. Sludge from the centrifuge also contains a high content of nutrients such as nitrogen, phosphorus, potassium and magnesium because of DAP added.

Table 4.24: Wastewater weight of Factory A and Factory B

No	Parameter	Weight (kg)		Maximum load (kg)*
		Factory A	Factory B	
1	BOD_5	4.4	0.4	4
2	COD	7.8	3.2	10
3	TSS	5.6	1.4	4
4	NH_3-Total	1.7	0.1	0.6
5	N-Total	2.7	0.5	1

(*)**Regulation of the Ministry of Environment Republic of Indonesia, Kep-51/MEN LH/10/1995**

4.5.5 Summary Overall Process Flow in Natural Rubber Latex Concentrate Processing

Figure 4.21 and Figure 4.22 are summarize of all material, energy, water air emission and wastewater involved in natural rubber latex concentrate processing of Factory A and Factory B.

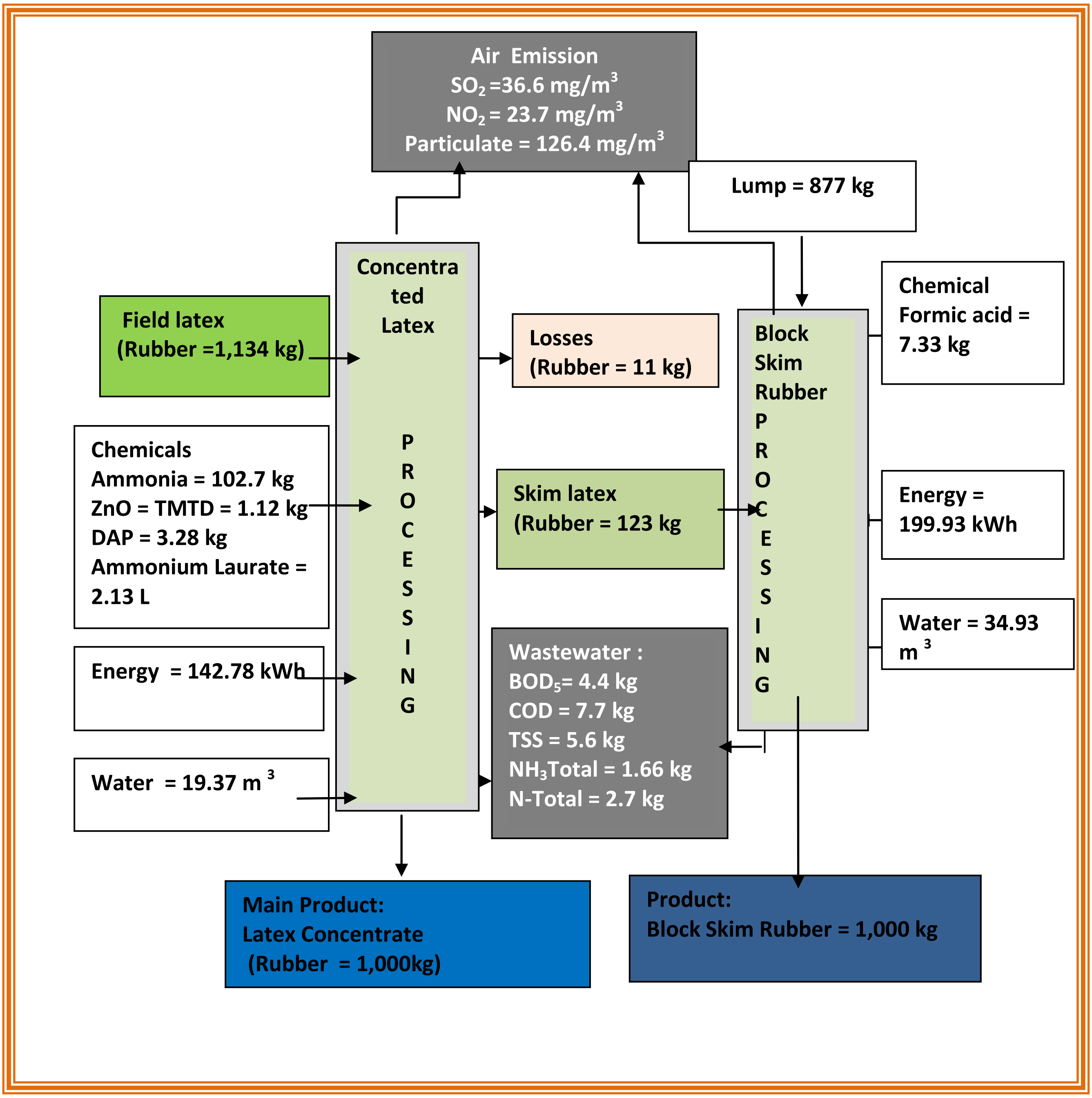


Figure 4.21: Overall Process Flow in Natural Rubber Latex Concentrate Processing of Factory A

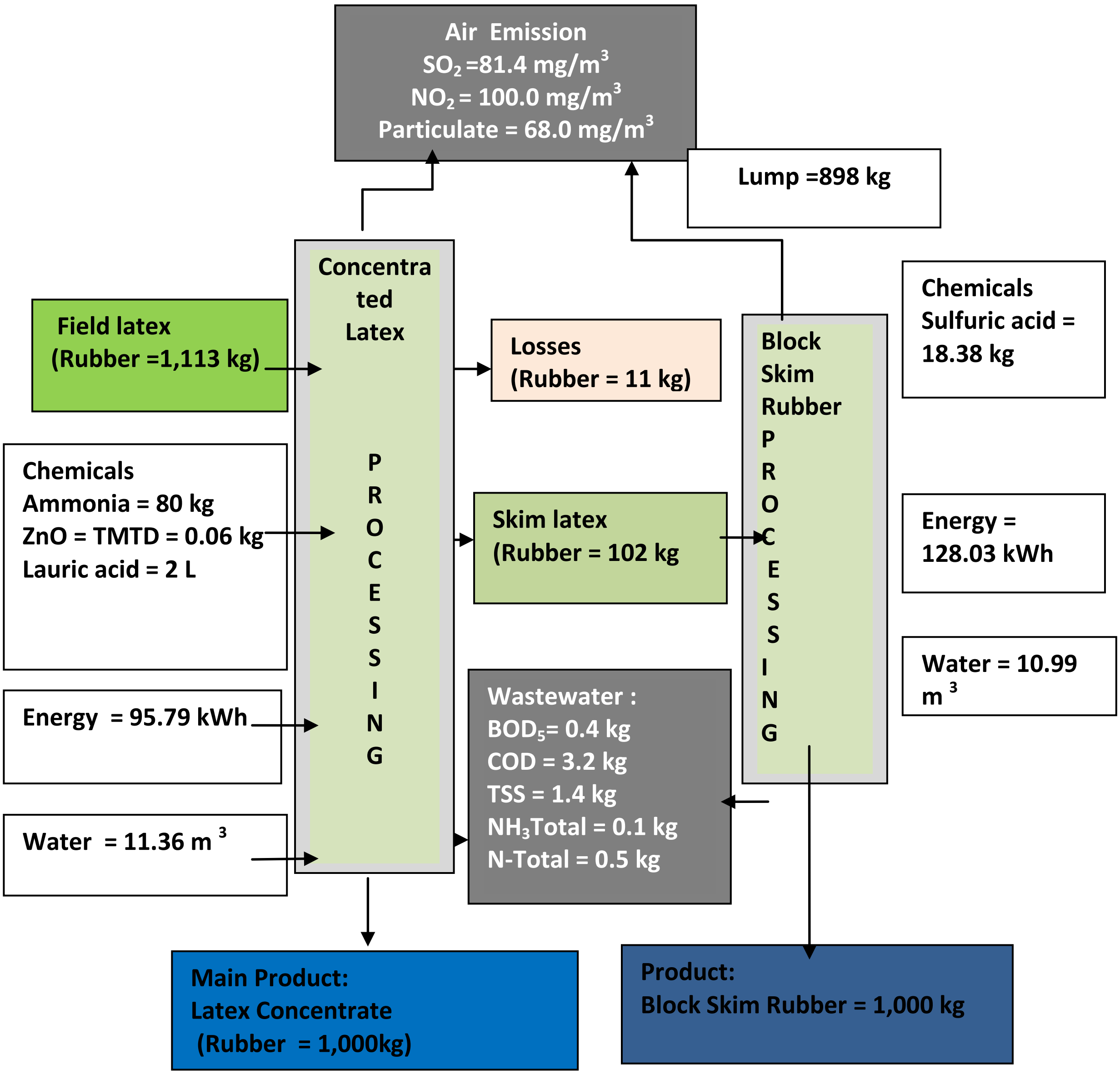


Figure 4.22: Overall Process Flow in Natural Rubber Latex Concentrate Processing of Factory B

4.6 Life Cycle Impact Assessment (LCIA)

Life cycle impact assessment is calculated using Eco-Indicator 99, with Hierarchical (HI) version as a damage model.

4.6.1 Characterization

According to Eco-Indicator 99, characterization consists of 11 impact categories that give impact to air, water and soil: namely, carcinogen, respiratory organics, respiratory inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals, and fossil fuels (M. Goedkoop, & Spriensma, R, 2001; M. Goedkoop, Schryver, A., & Oele, M, 2008).

Table 4.25 shows characterization of LCIA in natural rubber latex concentrate processing Factory A and Factory B with functional unit producing of 1,000 kg latex concentrate and 1,000 kg block skim rubber.

Table 4.25: Characterization of Natural Rubber Latex Concentrate Processing in Factory A and Factory B

Impact category	Unit	Latex Concentrate		Block Skim Rubber	
		Factory A	Factory B	Factory A	Factory B
Carcinogens	DALY	3.4059E-05	2.3770E-05	8.0705E-06	3.7113E-06
Resp. organics	DALY	1.3337E-07	9.8114E-08	1.1852E-07	9.8061E-08
Resp. in-organics	DALY	0.0001	7.3307E-05	2.0881E-05	2.9596E-05
Climate change	DALY	4.8405E-05	3.5581E-05	7.8731E-06	3.6023E-06
Radiation	DALY	3.6249E-07	2.4197E-07	4.228E-07	1.6861E-07
Ozone layer	DALY	3.5327E-08	2.6120E-08	4.2198E-08	3.8597 E-08
Ecotoxicity	PAF*m2yr	111.3411	72.8321	11.9393	7.8349
Acidification/ Eutrophication	PDF*m2yr	2.1592	1.5312	0.5582	0.6891
Land use	PDF*m2yr	2.3302	1.6709	0.8161	0.3333
Minerals	MJ surplus	6.5814	4.5147	0.8535	0.6462
Fossil fuels	MJ surplus	586.0969	100.3457	100.3457	50.6558

Generally, processing of natural rubber causes many environmental impacts to air, water and odor pollution (Tekasakul, 2006). Addition of ammonia in latex concentrate processing causes a strong smell which will affect the respiratory system of workers. Addition of acid to coagulate the rubber in skim latex causes the effluent to become acidic and there are many other impacts caused by natural rubber processing as describe below.

Impact of Factory A on carcinogens, respiratory organic, respiratory inorganic, climate change, radiation, ozone layer is very small (close to zero), which means causing no impact to human health. According to Goedkoop and Spriensma (2001) , Goedkoop, ,

(2008) , disability scale runs from $0 \leq DALY \leq 1$, where zero means healthy and one means death. Impact value on ecotoxicity of latex concentrate process separation amounted to 111.3411 PAF*m^2yr and is about 10 times larger than the processing of block skim rubber. The PAF unit shows the percentage of species are exposed to a concentration above No Observed Effect Concentration (NOEC). This means high value of PAF will increase the number of species that are affected (M. Goedkoop, & Spriensma, R, 2001). Impact to ecotoxicity gives stress to the ecosystem caused by use of chemical. Impact on ecotoxicity by latex concentrate separation predominantly comes from use of ammonia which is equal to 91.1965 PAF*m^2yr and for manufacturing block skim rubber, it is derived from use of formic acid as coagulant with a value 4.4794 PAF m^2yr*and plastic wrap 4.5773 PAF*m^2yr. Impact on minerals and fossil fuels on the separation process during latex concentration is also dominated by ammonia as preservatives. For block skim rubber manufacturing impact on minerals derived from water, impact on fossil fuel is derived from the use of formic acid with a value of 49.124 MJ Surplus and plastic wrap 43.9574 MJ Surplus.

Impact of Factory B is the same as impact of Factory A, in which carcinogens, respiratory organic, respiratory inorganic, climate change, radiation, ozone layer are very small (close to zero), which means causing no impact to human health. Impact value on ecotoxicity of latex concentrate process separation amounted to 72.8321 PAF*m^2yr and is about 10 times larger than the manufacture of block skim rubber. Impact to ecotoxicity gives stress to the ecosystem caused by use of chemical. Impact on ecotoxicity from latex concentrate separation predominantly comes from use of ammonia which is equal to 71.0392 PAF*m^2yr. Impact on manufacturing block skim rubber is derived from sulfuric acid as coagulant with a value 2.2354 PAF*m^2yr and plastic packaging 4.5773 PAF*m^2yr. Impact on minerals and fossil fuels on the separation of latex concentrate is also dominated by ammonia as preservative.

Impact to block skim rubber manufacturing for minerals is 79.66% derived from sulfuric acid and impact to fossil fuel is 86.78% is derived from the use of plastic packaging with a value of 43.9575 MJ Surplus.

4.6.2 Normalization of Characterization

Normalization shows the relative impact value of the total impact from a country or a region as a reference in one year and expressed as person equivalents (Yusoff, 2005) The normalization value is based on European standards. The number of impact categories that is already normalized shows the number of person affected in one year.

Normalization of impact categories for Natural Rubber Latex Concentrate Processing Factory A and Factory B is as shown in Table 4.26 and Fig 4.23.

Table 4.26: Normalization of Characterization of Natural Rubber Latex Concentrate Processing in Factory A and Factory B

Impact Category	Latex Concentrate		Block Skim Rubber	
	Factory A	**Factory B**	**Factory A**	**Factory B**
Carcinogens	3.8861E-03	2.7121E-03	9.2084E-04	4.2346E-04
Resp. organics	1.5217E-05	1.1195E-05	1.3523E-05	1.1189E-05
Resp. inorganics	1.1169E-02	8.3643E-02	2.3825E-03	3.3769E-03
Climate change	5.5523E-03	4.0598E-03	8.9833E-04	4.1102E-04
Radiation	4.1361E-05	2.7608E-05	4.8241E-05	1.9238E-05
Ozone layer	4.0308E-06	2.9803E-06	4.8148E-06	4.4039E-06
Ecotoxicity	1.9462E-03	1.2731E-03	2.0870E-04	1.3695E-04
Acidification/ Eutrophication	3.7743E-04	2.6765E-04	9.7576E-05	1.2045E-04
Land use	4.0731E-04	2.9207E-04	1.4266E-04	5.8266E-05
Minerals	8.7204E-04	5.9820E-04	1.1309E-04	8.5620E-05
Fossil fuels	7.7658E-02	5.7363E-02	1.3296E-02	6.7119E-03

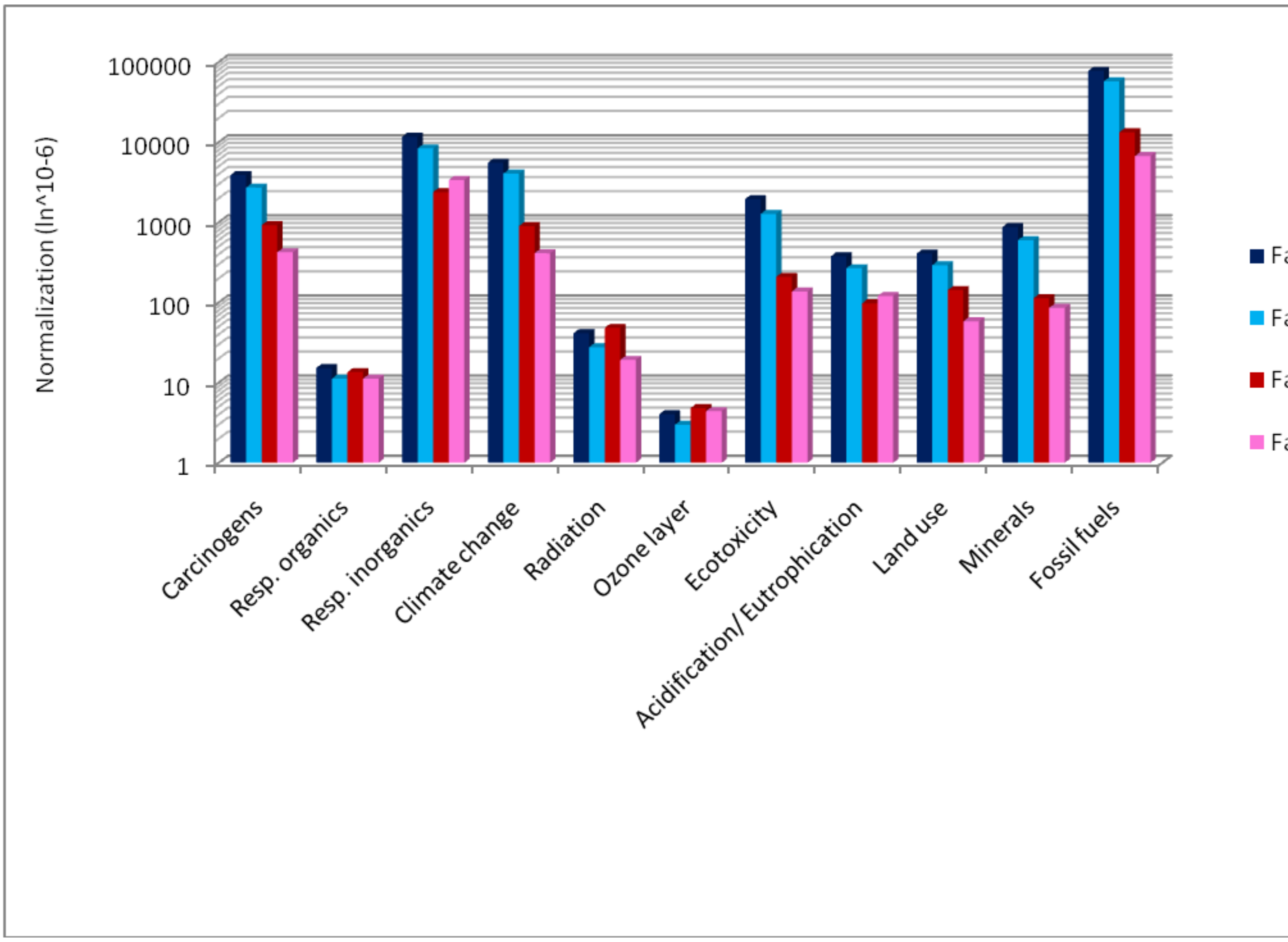


Figure 4.23: Normalization of Characterization of Natural Rubber Latex Concentrate Processing in Factory A and Factory B

According to Table 4.24, impact from fossil fuel for Factory A is higher than impact to respiratory inorganic followed by climate change, carcinogens and ecotoxicity. Ammonia gives significant impact to all impact categories; being approximately 80 - 90% compared to another input material. The greatest impact of ammonia on fossil fuel is (7.31E-02) followed by the impact of respiratory inorganic at (1.17E-02), climate change at (5.52E-03), carcinogens at (3.89E-03) and ecotoxicity at (1.59E-03). In this study use of electricity gives 0.37% smaller impact than ammonia. Ammonia is used as preservative in latex to prevent coagulation. Based on Jawjit et al. study by (2012) electric consumption, ammonia and use of DAP are the activities that cause the greatest impact. This is in contrast with this research because the amount of ammonia is significantly higher compared to Jawjit's while electricity is almost the same. Thus for this study ammonia is found to be the greatest source of impact in latex concentrate processing.

Impact to fossil fuel as the highest impact in block skim rubber processing comes from formic acid being (6.51E-03) and plastic (5.82E-03). Source of impact to respiratory inorganic is also derived from plastic at (9.96 E-04) and formic acid at (8.39E-04). Meanwhile the other impact categories are very low (< 1 E-04), so they can be ignored. Formic acid generally gives greater impact than other input materials such as plastic packaging, water, and electric. Coagulation process can basically take place without the use of formic acid, but requires a longer time. Consideration needs to be taken to avoid environmental damage or gives benefit, and this will discussed in the following section in eco-efficiency.

Figure 4.23 shows that in latex concentrate processing of Factory B, fossil fuel provides the highest impact followed by respiratory inorganic, climate change and carcinogen. Impact to fossil fuel has the value of (5.7363E-02), which means there is impact to (5.7363E-02) persons within one year period. Ammonia contributes impact more than 90% in almost all the impact categories which provides the greatest impact on fossil fuel that is equal to (5.69E-02) followed by the impact of respiratory inorganic at (8.17E-03), climate change at (3.99E-03), carcinogens at (2.57E-03) and ecotoxicity at (1.24 E-03). In this study the use of electricity contributes 0.32% smaller impact to fossil fuel compared to ammonia.

Meanwhile, for block skim rubber-making processing in Factory B, the greatest impact occurs in fossil fuel, followed by respiratory inorganic, carcinogens, climate change, ecotoxicity and acidification/ euthrophication. Impact to fossil fuel derived from the use of plastic packaging is (5.82E-03), followed by the use of sulfuric acid which is used as coagulant to coagulate skim latex. Impact of respiratory inorganic, derived from sulfuric acid is (2.19E-03). In general, plastic and sulfuric acid gave negative impacts in the impact categories such as carcinogens, climate change, ecotoxicity and acidification/ euthriphication although in smaller numbers ranging from (1E-05) to (1E-04).

4.6.3 Damage Assessment

Damage assessment consists of impact categories which involve three types of damages:

- Damage to Human Health, to show number of years lived taken by disability and the number of years of life lost, which is expressed in units Disability Adjusted Life Years (DALYs). The impact categories under damage to Human Health are:

carcinogens, respiratory organic, respiratory inorganic, climate change, radiation, ozone layer.

- Damage to Ecosystem Quality, to show the species is missing in one area in certain period. The impact categories under damage to Ecosystem quality are: ecotoxicity, acidification/eutrophication, landuse.
- Damage to Resources, to show a surplus of energy needed that must be replaced for the future to extract minerals or fossil fuels.

Table 4.27 shows the damage assessment of Life Cycle Impact Assessment in Natural Rubber Latex Concentrate of Factory A and Factory B and the graphical representation of the table is shown in Figure 4.24.

Damage to Human Health in Factory A derived from ammonia is 0.00016 DALY, 12.9725 PDF*m^2yr damage to Ecosystem Quality and 557.2908 MJ Surplus damage to Resources. Ammonia gives damage value greater than 80% compared to all the other materials used in latex concentrate processing.

Formic acid and plastics packaging provide damage in block skim rubber manufacturing in which formic acid gives 40% impact on human health, 49% impact on the resources and 34% impact on eco-system quality. Plastic packaging is used to cover the block skim rubber gives 32% impact on human health, 32% impact on ecosystem quality and 43% impact on resource. The three damage categories cannot be compared with each other because different unit are used.

While for Factory B, ammonia contributes more than 90% damage, which is the highest damage for all damage categories in latex concentrate processing. Plastic wrapping contributes 86% damage to resources and 45% to ecosystem quality, and sulfuric acid contributes 58% damage to human health and 38% to ecosystem quality in block skim rubber processing.

Table 4.27: Damage Assessment in Natural Rubber Latex Concentrate Processing in Factory A and Factory B

Damage Category	Unit	Latex Concentrate		Block Skim Rubber	
		Factory A	Factory B	Factory A	Factory B
Human Health	DALY	0.018E-02	0.013E-02	3.7408E-05	3.7214E-05
Ecosystem Quality	PDF*m^2yr	15.6235	10.4853	2.5683	1.8059
Resources	MJ surplus	592.6783	437.4452	101.1992	51.3020

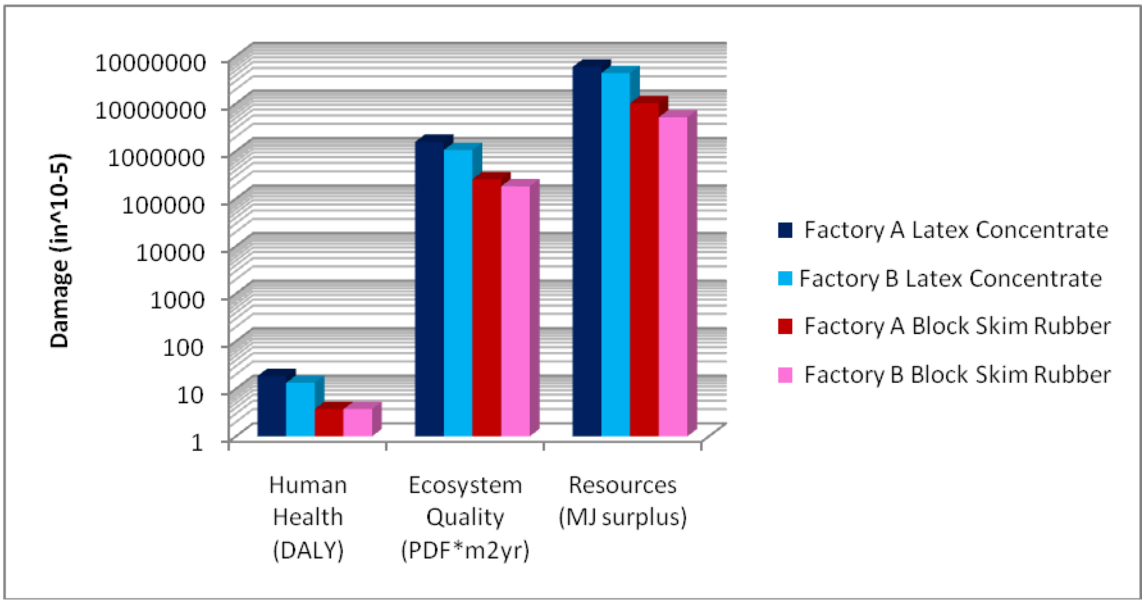


Figure 4.24: Damage Assessment of Latex Concentrate Processing in Factory A and Factory B

4.6.4 Normalization Damage Assessment

Normalization of damage categories in Natural Rubber Latex Concentrate Processing for Factory A and Factory B is shown in Table 4.26 and Figure 4.25. It is clear that

Resources and Human Health are dominating damages both for latex concentrate processing and block skim rubber processing.

Ammonia contributes damage of 0.0738 PE (94.03%) in resources and 0.019 PE (89.60%) to human health, which means 0.0738 persons in one year are affected under resources and 0.019 persons in one year under human health in Factory A. Overall, ammonia contributes the highest impact (92.80%) with the total impact of 0.1024 PE.

High impact in block skim rubber processing in Factory A is derived from formic acid that contributes 0.0066 PE (49%) to resources and wrapping plastic contributes 0.0058 PE (43%) to resources. Overall, formic acid gives impact of 47%, wrapping plastic 41% and water 10% with the total impact 0.0181 PE.

According to Jawjit et al. (2012), electricity causes 42% impact to human health and 54% to resources while ammonia contribute 14% to human health and 25% impact to resources. Lauric acid as coagulant was found to be the main cause of ecosystem quality problems (28%). Plastic as a covering for block rubber was not included in Jawjit's study.

Table 4.28: Normalization of Damage Assessment Natural Rubber Latex Concentrate Processing in Factory A and Factory B

Damage Category	Unit	Latex Concentrate		Block Skim Rubber	
		Factory A	Factory B	Factory A	Factory B
Human Health		0.0211	0.0152	0.0043	0.042
Ecosystem Quality		0.0027	0.0018	0.0004	0.0003
Resources		0.0785	0.0580	0.0134	0.0068

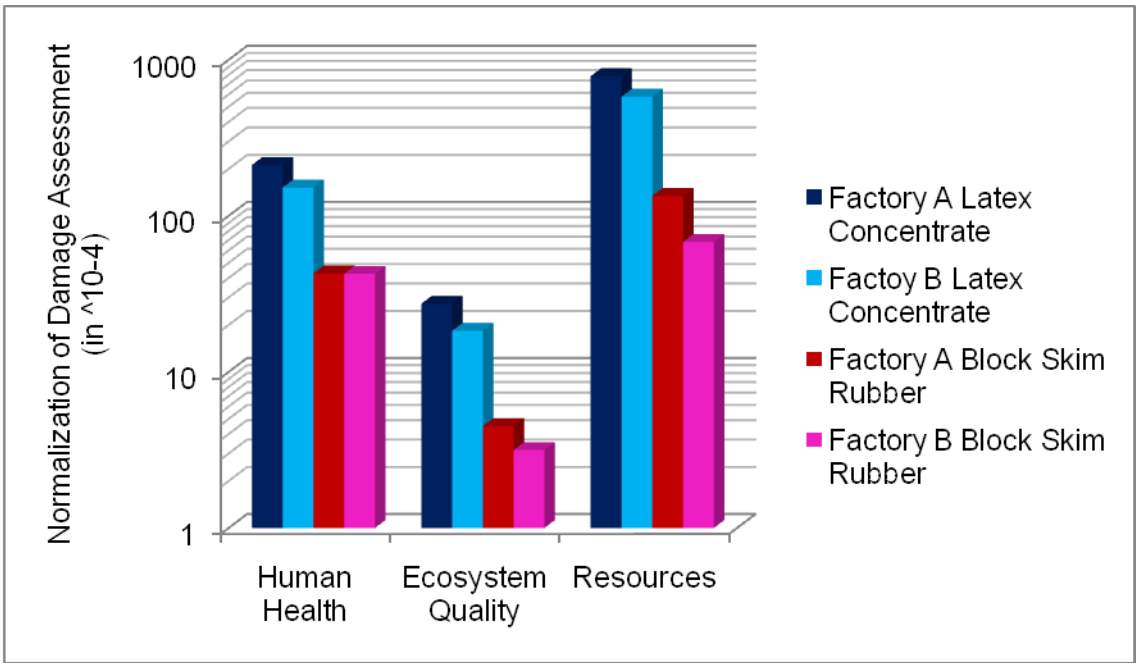


Figure 4.25: Normalization Damage Assessment of Latex Concentrate Processing in Factory A and Factory B

Resources has the highest damage both in concentrated latex processing and block skim rubber processing in Factory B. The source of damage in latex concentrate processing derived from ammonia has a value of 0.0575 PE (99.24%). Overall, ammonia gives a very dominant impact amounting to 98.77% with the total impact of 0.0750 PE.

Block skim rubber processing in Factory B contributes high damage in resources caused by plastic packaging at 0.0058 PE(85.75%) and sulfuric acid contributes damage of 0.0042PE (58.28%) in human health. Overall, plastic packaging (64.66%) provides the greatest impact followed by sulfuric acid (27.51%) with the total impact 0.0113 PE.

From the information above ammonia contributes a very dominant effect on latex concentrate processing in which Factory A give greater impact than Factory B. The use of plastics and acid as coagulant contribute to impact in block skim rubber processing.

4.6.5 Weighting

4.6.5.1 Weighting per impact category

Weighting is done following the procedures from Eco-Indicator 99, to know the important categories after normalization, and makes it possible to directly compare the categories. The unit of weighting is point in which one point indicate the weighted impact from one mille-person equivalent (the impact per year from 1/1,000 persons).

Weighting in Natural Rubber Latex Concentrate processing of Factory A and Factory B is shown in Table 4.29 and Figure 4.26. After weighting, fossil fuel (75%) is still the most affected impact category, followed by respiratory inorganic (11%), climate change (5%), carcinogens(4%) and ecotoxicity (3%) from total impacts of 30.9985pt in latex concentrate processing. The weighted value to fossil fuels is 23.2974 pt, indicating impact equivalent to 0.023 persons (in Europe) in a year, the majority of 21.9274 pt (75%) cause is related to use of ammonia. Ammonia contributes impact in respiratory in-organics with weighting value of 3.1476 pt, the same as 10% from total impact in weighting. Impact because of using electricity after weighting is nearly zero compared to ammonia.

In block skim rubber processing, fossil fuel is the highest impact, followed by respiratory inorganics, carcinogens and climate change. Impacts to fossil fuel comes from formic acid at 1.9527 pt (49%) and wrapping plastic at 1.7473 pt (43.81%). Overall impact to block skim rubber processing in Factory A comes from formic acid at 2.5504 pt (46.52%) and plastic packaging at 2.2218 pt (40.45%). According to Varžinskas et al., (2009) plastic packaging gives the most impact during manufacturing (5.1 mPt), while in usage 0.31 mPt and disposal 0.025 mPt. It appears that impact during manufacturing is bigger than usage and disposal, so the use of plastic packaging should be as efficient as possible. Excessive size and thickness will have a large impact on the environment.

Table 4.29: Weighting per impact category Natural Rubber Latex Concentrate Processing in Factory A and Factory B

Impact Category	Unit	Latex Concentrate		Block Skim Rubber	
		Factory A	Factory B	Factory A	Factory B
Carcinogens	Pt	1.1658	0.8136	0.2763	0.1270
Resp. organics	Pt	0.0046	0.0034	0.0041	0.0034
Resp. inorganics	Pt	3.5062	2.5093	0.7148	1.0131
Climate change	Pt	1.6569	1.2179	0.2695	0.1233
Radiation	Pt	0.0124	0.0083	0.0145	0.0058
Ozone layer	Pt	0.0012	0.0009	0.0014	0.0013
Ecotoxicity	Pt	0.7785	0.5092	0.0838	0.0548
Acidification/ Eutrophication	Pt	0.1510	0.1071	0.0390	0.0482
Land use	Pt	0.1629	0.1168	0.0571	0.0233
Minerals	Pt	0.2616	0.1795	0.0339	0.0257
Fossil fuels	Pt	23.2974	17.2090	3.9887	2.0136

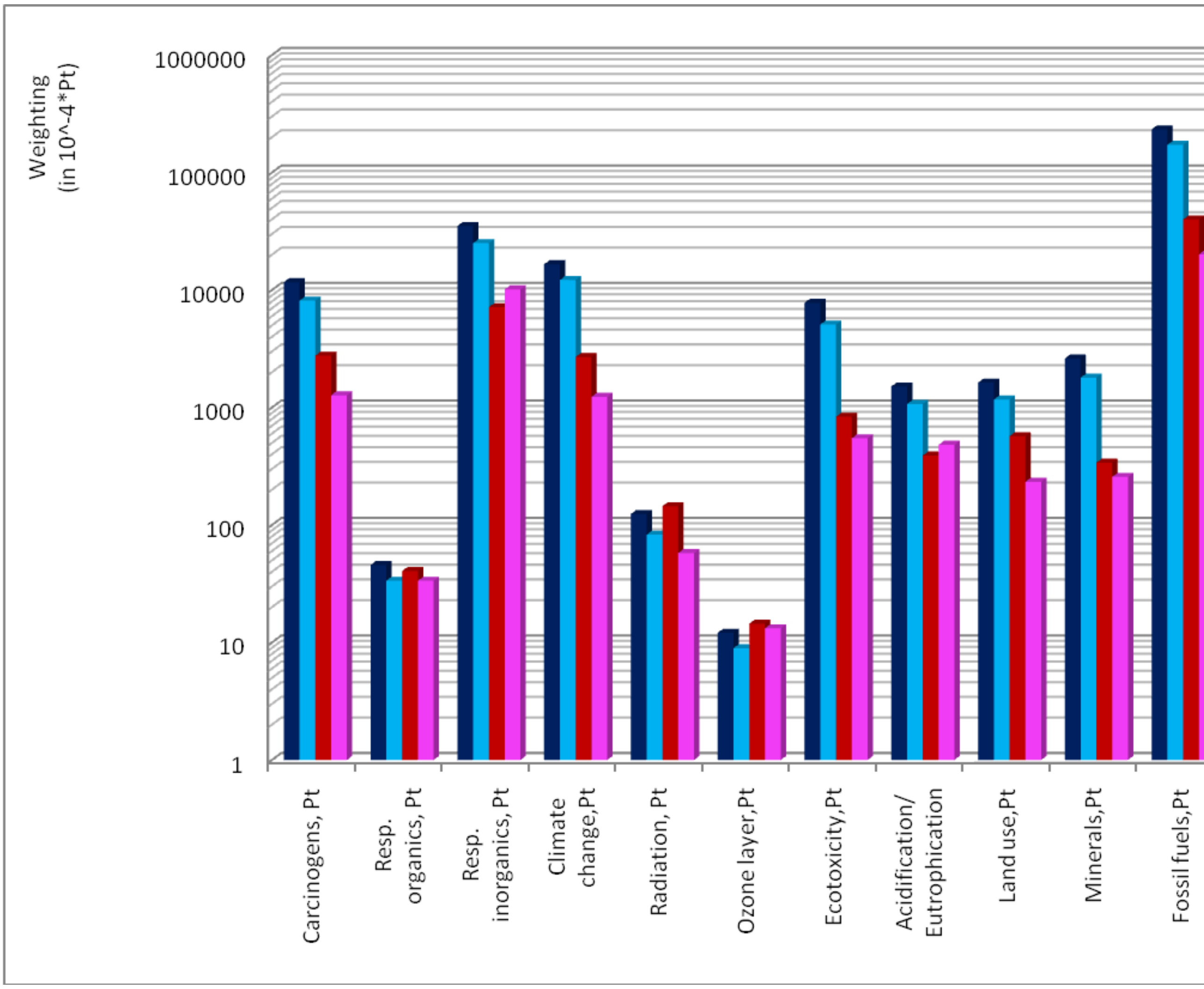


Figure 4.26 : Weighting per impact category Natural Rubber Latex Concentrate Processing in Factory A and Factory B

Impact to fossil fuels in Factory B is the highest followed by respiratory in-organics, climate change, carcinogens and ecotoxicity in latex concentrate processing. Ammonia affects impact most in all impact categories.

After weighting, fossil fuel (76%) is still the most affected impact category in Factory B, followed by respiratory inorganic (11%), climate change (5%), carcinogens(4%) and ecotoxicity (2%) from total impacts of 22.675pt in latex concentrate processing. The weighted value to fossil fuels is 17.209 pt, indicating impact equivalent to 0.017 persons (in Europe) in a year. The majority of 217.081 pt (75%) is caused by use of ammonia. Ammonia contributes impact in respiratory inorganics in weighting value of 2.4519 pt, the same as 11% from total impact in weighting. Impact because of electricity usage after weighting is near to zero compared to ammonia.

Block skim rubber processing contributed the most impact to fossil fuels, followed by respiratory in-organics, carcinogens and climate change. Plastic packaging contributes the highest impact (64%), and sulfuric acid (28%) from the total impacts of 3.4393 pt. Plastic packaging gives impact most in fossil fuels and sulfuric acid gives impact most to respiratory in-organics.

4.6.5.2 Weighting not per impact category

Weighting not per impact category also known as weighting to three parameters of damage for Factory A and Factory B is shown in Table 4.30 and represented in Figure 4.27. Weighting to resources is 76% from total weighting and is the highest, followed by human health at 20% in latex concentrate processing. Ammonia contributes the highest impact at 93% from total weighting of 30.9985 pt. Ammonia contributes 94% impact in resources, 90% in human health and 83% in ecosystem quality. Impact from other materials is less than 1%, and it can be neglected. This is different from latex concentrate production in Thailand, where impact is mainly caused by electricity (49%) and followed by ammonia (22%) (W. Jawjit, et al., 2012).

Weighting to resources is 73% from total weighting of 5.4827 pt and is the highest, followed by human health (23%) in block skim rubber processing. The activity that contributes impact to environment are formic acid which contributes 47% especially in resources, wrapping plastics contributes 40% mainly in resources and water at 10% based on total weighting.

Table 4.30: Weighting not per impact category Natural Rubber Latex Concentrate Processing in Factory A and Factory B

Damage Category	**Unit**	**Latex Concentrate**		**Block Skim Rubber**	
		Factory A	**Factory B**	**Factory A**	**Factory B**
Human Health	Pt	6.3472	4.5534	1.2804	1.2739
Ecosystem Quality	Pt	1.0924	0.7331	0.1796	0.1262
Resources	Pt	23.5590	17.3884	4.0227	2.0393

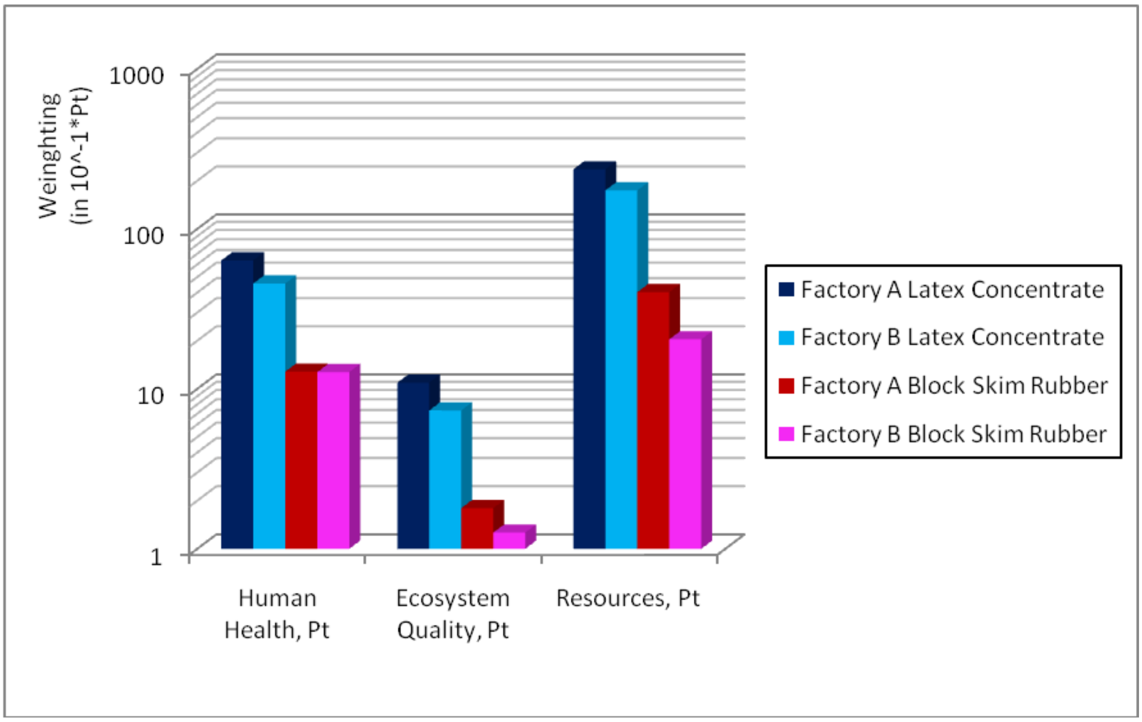


Figure 4.27 : Weighting not per impact category Natural Rubber Latex Concentrate Processing in Factory A and Factory B

Ammonia contributes the highest weighting of 99% from total weighting of 22.675, and ammonia contributes weighting of 76% in resources and 20% in human health in latex concentrate processing in Factory B. Weighting from other materials is less than 1% and it can be neglected.

Weighting to resources is 59% from total weighting and is the highest, followed by human health at 37% in block skim rubber processing. Plastic packaging contributes the highest impact (64%) followed by sulfuric acid (28%) in total weighting. Plastic packaging contributes weighting of 51% in resources, formic acid contributes 12% to human health from total weighting and sulfuric acid contributes weighting of 22% to human health from total weighting. Weighting to other damage categories by other materials is very small, being less than 5%.

4.7 Eco-Efficiency

4.7.1 Calculation of Eco-Efficiency

The Eco-Efficiency concept is suitable for the industrial world because its practical approach makes it possible to balance environmental and economic benefits (Maxime, 2006). According to WBCSD (2000), eco efficiency is calculated as Eq. (2):

Eco-Efficiency = (Product or Service Value/ Environmental Impact)

In this research product or service value is functional unit or mass of field latex to process, and environmental impact as impact categories or damages in Eco-Indicator 99. Based on the Life Cycle Impact Assessment for the Natural Rubber Latex Concentrate Processing for Factory A and Factory B, there were some impact categories that are significant and some are very small and can be neglected.

Table 4.31 shows the weighting in natural rubber latex concentrate processing in Factory A and Factory B and Table 4.32 displays percentage of impact categories which compare impact category to the total impact. Percentage of each impact category to the total impact on each factory in latex concentrate processing is almost similar, in which total impact to Factory A is 30.9985 pt and Factory B is 22.675 pt. Fossil fuels is very dominant in impact categories and has the highest percentage value followed by respiratory in-organics, climate change and ecotoxicity.

Respiratory organics, radiation, ozone layer due to the latex concentrate processing for both Factory A and Factory B have very small impact compared to the total impact and could be neglected in this research. Therefore the environmental parameters that influence environmental impact in latex concentrate processing selected for eco-efficiency calculations are: carcinogens, respiratory inorganics, climate change, ecotoxicity, acidification/ euthrophication, land use, minerals, and fossil fuels. Consequently for latex concentrate processing, impact has taken 8 from a total of 11 impacts to show eco-efficiency performance categories.

In block skim rubber processing the value of organic respiratory, radiation, ozone layer are very small. Therefore the impacts can be neglected compared to the other categories. Similarly, for block skim rubber processing has impacts taken 8 from a total of 11 categories to show eco-efficiency performance.

Table 4.31: Weighting Impact Categories of Natural Rubber Latex Concentrate Processing in Factory A and Factory B

Impact Category	Unit	Latex Concentrate		Block Skim Rubber	
		Factory A	Factory B	Factory A	Factory B
Total	Pt	30.9985	22.6750	5.4827	3.4394
Carcinogens	Pt	1.1658	0,8136	0.2763	0,1270
Resp organics	Pt	0.0046	0.0034	0.0041	0.0034
Resp. inorganics	Pt	3.5062	2,5093	0.7148	1,0131
Climate change	Pt	1.6569	1,2179	0.2695	0,1233
Radiation	Pt	0.0124	0.0083	0.0145	0.0058
Ozone layer	Pt	0.0012	0.0009	0.0014	0.0013
Ecotoxicity	Pt	0.7785	0,5092	0.0835	0,0548
Acidification/ Eutrophication	Pt	0.1510	0,1071	0.0390	0,0482
Land use	Pt	0.1629	0.1168	0.0571	0.0233
Minerals	Pt	0.2616	0.1795	0.0339	0.0257
Fossil fuels	Pt	23.2974	17,2090	3.9887	2,0136

Table 4.32: Percentage of Weighting Impact Categories of Natural Rubber Latex Concentrate Processing in Factory A and Factory B

Impact Category	**Unit**	**Latex Concentrate**		**Block Skim Rubber**	
		Factory A	**Factory B**	**Factory A**	**Factory B**
Total	Pt	30.9985	22.6750	5.4827	3.4394
Carcinogens	%	3.76	3.59	5.04	3.69
Resp organics	%	0.01	0.01	0.07	0.10
Resp. inorganics	%	11.31	11.07	13.04	29.45
Climate change	%	5.35	5.37	4.92	3.59
Radiation	%	0.04	0.04	0.26	0.17
Ozone layer	%	0.00	0.00	0.03	0.04
Ecotoxicity	%	2.51	2.25	1.52	1.59
Acidification/ Eutrophication	%	0.49	0.47	0.71	1.40
Land use	%	0.53	0.52	1.04	0.68
Minerals	%	0.84	0.79	0.62	0.75
Fossil fuels	%	75.16	75.89	72.75	58.54

Eco-efficiency in natural rubber latex concentrate processing is calculated based on the Eq. (2) is shown in Table 4.33 and the graph to represent the table is shown in Figure 4.28.

Table 4.33: Eco-Efficiency of Natural Rubber Latex Concentrate Processing of Factory A and Factory B based on Impact Categories

Impact Category	Eco-Efficiency (kg/Pt) Latex Concentrate		Eco-Efficiency (kg/Pt) Block Skim Rubber	
	Factory A	Factory B	Factory A	Factory B
Total	**1.966E+04**	**2.794E+04**	**9.358E+04**	**1.383E+05**
Carcinogens	8,578,E+02	1,229,E+03	3,620,E+03	7,872,E+03
Resp. inorganics	2,852,E+02	3,985,E+02	1,399,E+03	9,871,E+02
Climate change	6,035,E+02	8,211,E+02	3,711,E+03	8,110,E+03
Ecotoxicity	1,285,E+03	1,964,E+03	1,198,E+04	1,825,E+04
Acidification/ Eutrophication	6,624,E+03	9,341,E+03	2,562,E+04	2,075,E+04
Land use	6,138,E+03	8,560,E+03	1,752,E+04	4,291,E+04
Minerals	3,822,E+03	5,572,E+03	2,948,E+04	3,893,E+04
Fossil fuels	4,292,E+01	5,811,E+01	2,507,E+02	4,966,E+02

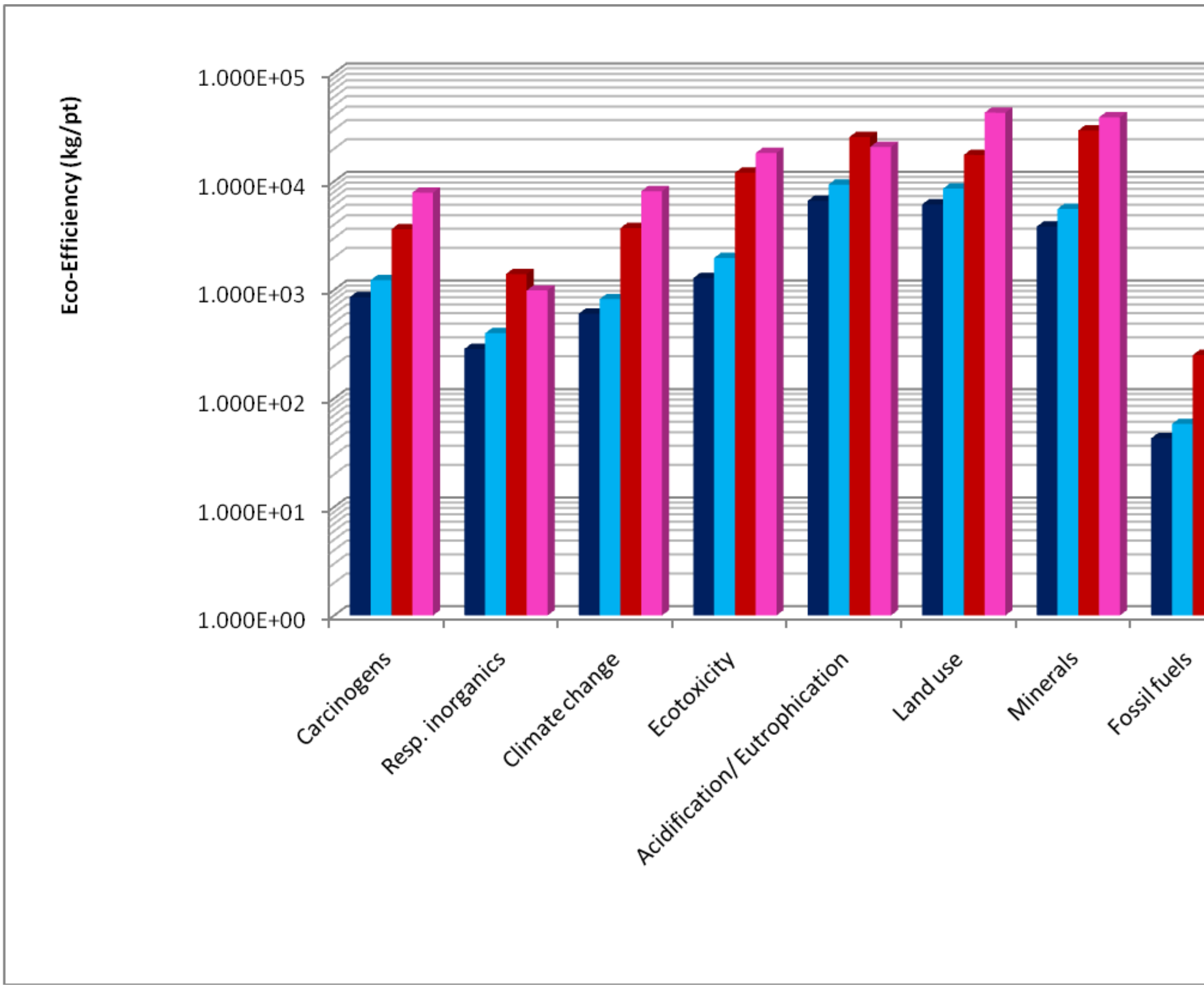


Figure 4.28: Eco-Efficiency of Natural Rubber Latex Concentrate Processing in Factory A and Factory B based on Impact Categories

Based on Eq.2 higher product or service value, and lower environmental impact will increase the value of eco-efficiency. Product or service value, in this research is mass of concentrated latex which should have high dry rubber content (DRC). There are several factors that determine dry rubber content (DRC) in latex concentrate processing, and it includes:

- *Chemical*: chemical serves as a preservative or stabilizer. Besides, it also bind metals that can disrupt the on going process.
- *Equipments*: equipments should work in accordance with the requirement. Centrifuge should have rotation of 6000 rpm, to ensure separation process has a high efficiency.

Environmental impacts are due to chemical, energy and water used in the process. Small environmental impact will be obtained when the amount of these three elements are small with maximized function of each element.

From Table 4.33, eco-efficiency for latex concentrate processing of Factory B is greater than Factory A in all impact categories. Ammonia is a compound that gives a significant impact of more than 90% in both factories resulting in small eco-efficiency value. The amount of ammonia is more in Factory A than Factory B that influence the eco-efficiency. Ammonia gives impact more in fossil fuels (75.2%) and respiratory in-organics (11.3%) for Factory A, while 75.3 % effect to fossil fuels and 10.8% effect to respiratory inorganic for Factory B.

Eco-efficiency of block skim rubber processing of Factory B is greater than Factory A. Formic acid contributes impact of 35.6% and plastic 31.9% to fossil fuels which will give small eco-efficiency value in Factory A. Respiratory inorganic also affect small eco-efficiency because of impact by formic acid 4.6% and plastic 5.5%. Plastic (50.8%) was found to be the main cause for impact to fossil fuels and sulfuric acid 19.1 % to respiratory in-organics that influence the eco-efficiency in Factory B.

Figure 4.28 shows that eco-efficiency in natural rubber latex concentrate of Factory B is better than Factory A.

Eco-efficiency as a function of three parameters of damage assessment can be seen in Table 4.34 and in Figure 4.29. It appears that damage to resource provides the worst eco-efficiency in natural rubber latex concentrate processing for both factories followed by human health problem. Therefore it needs to manage the resource and human health need to be properly managed to improve the eco-efficiency.

Table 4.34: Eco-Efficiency of Natural Rubber Latex Concentrate Processing in Factory A and Factory B based on Damage Assessment

Damage Category	Eco-Efficiency (kg/Pt) Latex Concentrate		Eco-Efficiency (kg/Pt) Block Skim Rubber	
	Factory A	Factory B	Factory A	Factory B
Human Health	157.5508	219.6171	780.9549	785.0200
Ecosystem Quality	915.4207	1364.0149	5568.7057	7919.5900
Resource	42.4467	57.5094	248.5912	490.3750

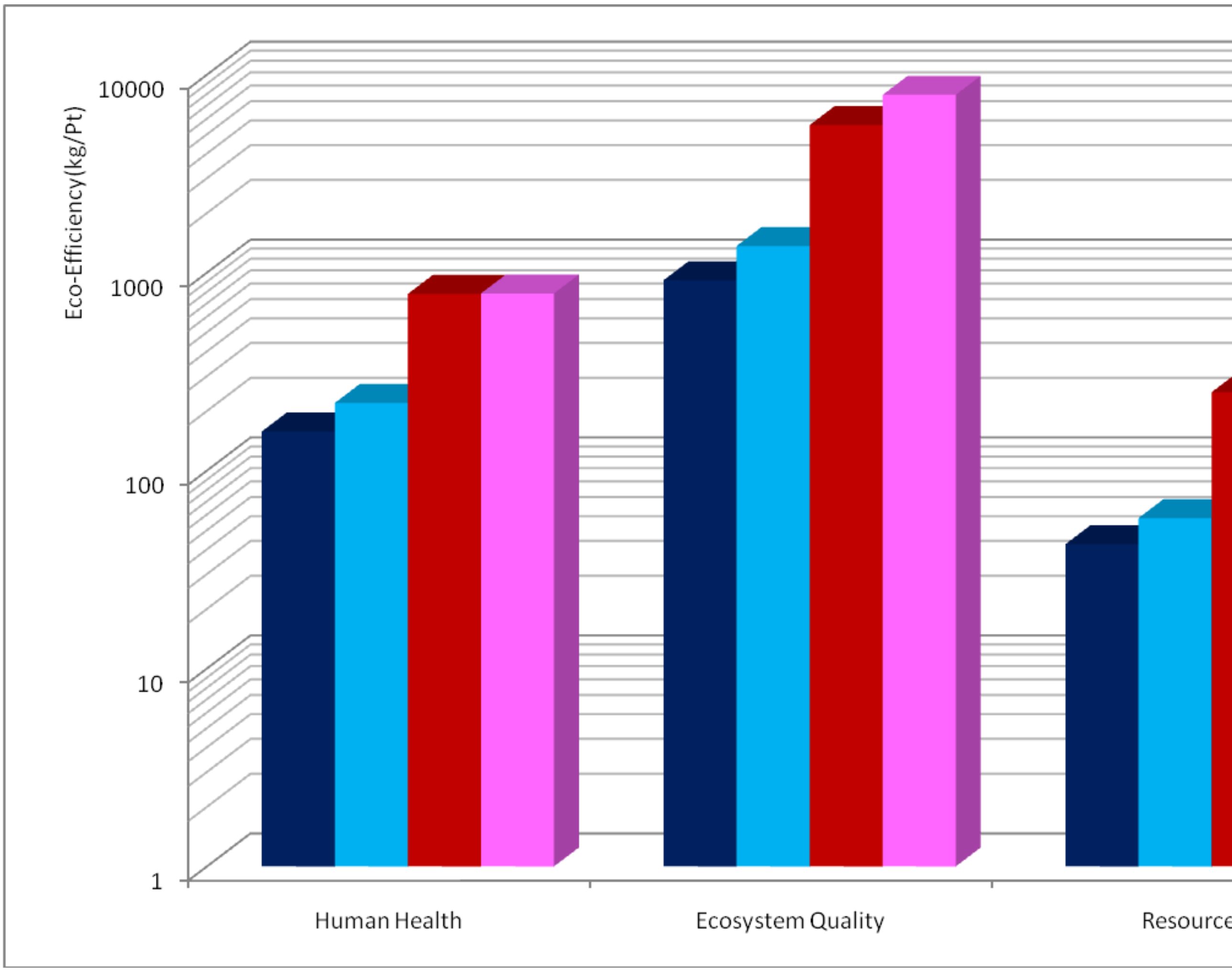


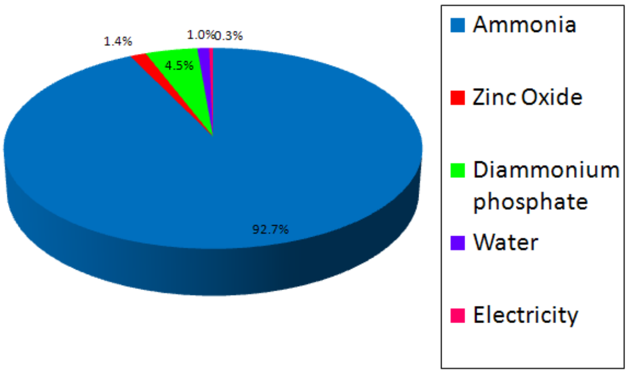
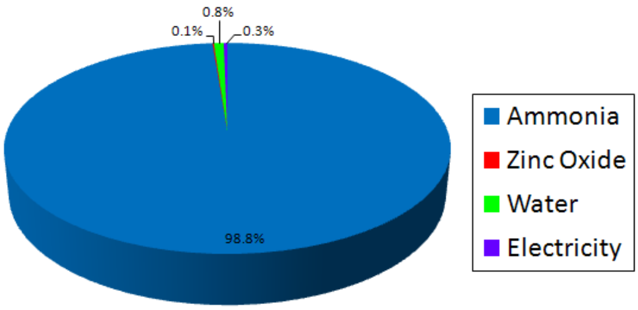
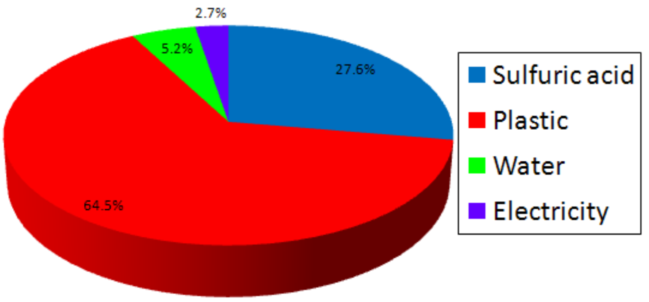
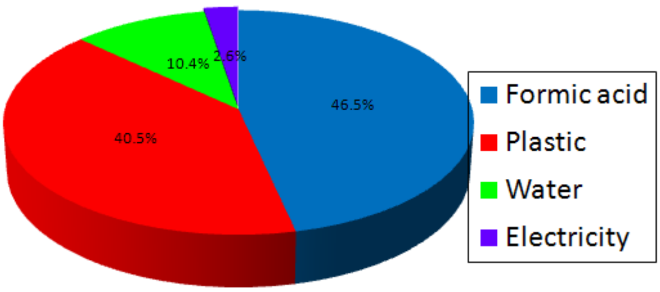
Figure 4.29: Eco-Efficiency of Natural Rubber Latex Concentrate Processing in Factory A and Factory B based on Damage Assessment

Basically the suitable use of raw materials and secondary materials in process industry will reduce waste, which in turn can reduce the impact on the environment. According to Table 4.35, when all impact categories or damage assessment is made in a single score, then the sequence of components that provides impact starting from high to low at Factory A for latex concentrate are : Ammonia 92.7%, Diammonium Phosphate 4.5%, Zinc Oxide 1.4 %, Water 1%, Electricity 0.3% with total impact of 30.998 pt. For block skim rubber processing, the sequence of impact is caused by: Formic acid 46.5%, Plastic 40.5%, Water 10.4% and Electricity 2.6% with total impact of 3.439 pt.

The same result is obtained for Factory B where the sequence of components that provide the impacts in the latex concentrate processing are: Ammonia 98.8%, Water 0.8%, Electricity 0.3% and Zinc Oxide 0.1% with total impact of 22.675 pt. The sequence impact in block skim rubber processing are: plastic 64.5%, sulfuric acid 27.6%, water 5.2% and electricity 2.7% with total impact of5.483 pt.

Percentage of the effect of chemicals, energy and water use in natural rubber latex concentrate processing based on the resulting impact is shown in Table 4.35.

Table 4.35: Effect of the chemicals, energy and water in Natural Rubber Latex Concentrate Processing

Percentage of the effect of chemicals, energy and water	**Diagram**
Latex Concentrate for Factory A with total Impact 30.998 pt	
Latex Concentrate for Factory B with total Impact 22.675 pt	
Block Skim Rubber for Factory B with total Impact 3.439 pt	
Block Skim Rubber for Factory A with total Impact 5.483 pt	

Ammonia is a compound which gives dominant impact on concentrated latex in Factory A and Factory B. Ammonia has a pungent odor that can damage health of workers', especially to the respiratory system. The smell of ammonia will also affect the community around the factory. Both factories are located near to settlement.

High amount of ammonia usage can be caused by:

- A longer interval period between tapping and separation process in the factory , due to the distance between plantation and factory.
- Quality of field latex entering the factory is highly uncertain due to weather condition. Therefore it is very difficult to set a fixed amount of ammonia.

Excess ammonia leads to high use of acid for neutralization in coagulation pond. The excess acid not only causes acidic effluent but also re-dissolves the rubber protein and causes delay in coagulation. The incomplete coagulation results in the loss of rubber particles into the effluent. Reduction of ammonia levels in skim latex can be done using the de-ammoniation tower with long trough length of 100 m, which can reduce levels of ammonia by 50% (2001). Deammoniation had been done before coagulation as one of the solutions to reduce ammonia in skim latex. Hence, use of ammonia must be properly quantified, so that sequential impact can be avoided.

Preparation and storage of ammonia are done under proper control. Ammonia are usually bought in a gas form, reaction with water to form ammonium hydroxide causes rise in temperature and ammonia will evaporate more easily. To prevent unnecessary loss, reaction must be done under low temperature.

To reduce loss due to evaporation of ammonia, ammonia solution should be placed in the chiller.

Diammonium phosphate is the second highest chemical that gives impact in Factory A, which can cause eutrophication. Magnesium is removed from the latex before centrifugation to ensure high quality latex concentrate, by the addition of diammonium phosphate (DAP). The exact amount of the salt should be used. A large amount of DAP added can cause decrease of the mechanical stability of products (Cecil, 2003). Reducing the amount of added DAP can cause lengthening of sedimentation time (W. Jawjit, et al., 2012). Lengthening of sedimentation from 10-12 hours to 20-24 hours will reduce 14%-19% impact to euthrophication (W. Jawjit, et al., 2012), therefore increase in eco-efficiency.

Contributors of impact in block skim rubber at Factory A are formic acid, plastic, water and electricity. Meanwhile contributors to impact on Factory B are: plastic, sulfuric acid, water and electricity.

The plastic used for packaging block skim rubber should be used with the precise size so that the volume and weight meet minimum desirable dimensions. This will lead to minimum impact to the environment (Mahat and MacRae, 1992).

4.7.2 Eco-Efficiency Indicator

Eco-Efficiency Indicator is determined by three factors: waste intensity, energy intensity and water intensity as shown in Table 4.36 and Figure 4.30 for Factory A and Factory B in natural rubber latex concentrate processing Calculation is done according to the equations (4), (5), (6) in Chapter III.

Table 4.36: Eco-Efficiency Indicator Factory A and Factory B in Natural Rubber Latex Concentrate Processing

Eco-Efficiency Indicator	Latex Concentrate		Block Skim Rubber	
	Factory A	**Factory B**	**Factory A**	**Factory B**
Waste Intensity (kg/kg)	0.0112	0.0108	Nil	Nil
Energy Intensity (kWh/kg)	0.1428	0.0958	0.20	0.1280
Water Intensity (m^3/kg)	0.0194	0.0116	0.0349	0.0110

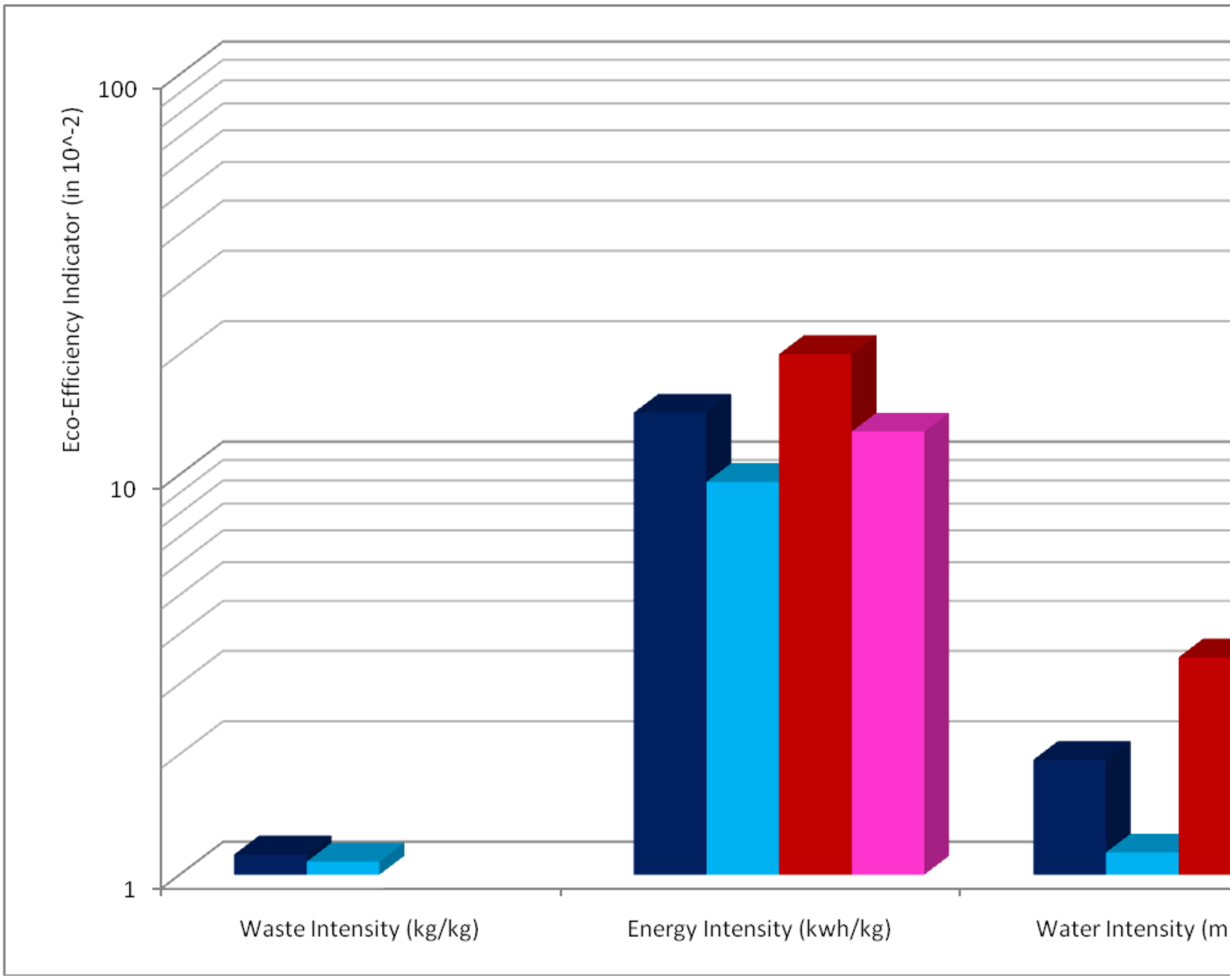


Figure 4.30: Eco-Efficiency Indicator of Natural Rubber Latex Concentrate Processing in Factory A and Factory B

4.7.2.1.Waste Intensity

The definition of waste here is rubber which did not participate as a product in latex concentrate and block skim rubber, which is also known as rubber losses. This definition is similar to DIW definition (DIW, 2001) , in which losses is defined as:

% lost DRC = (DRC in field latex (kg) - DRC in conc. latex (kg) - DRC in skim rubber (kg)/ DRC in field latex (kg)) x 100%.

Based on Table 4.34 waste in latex concentrate processing for both factories almost show the same losses, which is equal to 1% of rubber contained in the field latex. Waste rubber is usually taken from drainage system originating from coagulation to the wastewater treatment pond. Waste is usually sold at a low price. Waste intensity in Factory A is 0.0112 and Factory B 0.0108, which is almost the same for both factories. Waste intensity influences the amount of wastewater parameters, such as BOD_5, COD, TSS, N-Total and NH_3N (total ammonia) as shown in Table 4.22.

For the production of block skim rubber, there was no waste, because all the rubber entered to the first stage, Macerator in Factory A and Pre-breaker in Factory B, become block skim rubber as a product. It should be understood that wasteentails double payment, namely, cost of raw material and management or disposal of the waste (Das, 2005).

Based on Table 4.16 and Table 4.17 the dry rubber content of latex concentrate as the main product is in the range of 88% -90%, side product as coagulum 9% -11% and, losses 1% from DRC in field latex.

Reduction of waste can be achived in several ways:

- Rubber trap for coagulation pond should be able to work well, so there is no rubber passing into the channel towards wastewater treatment plant.
- The acid should be added as needed to coagulate rubber in skim latex completely.

4.7.2.2. Energy Intensity

The source of energy for industries in Indonesia comes from the government electricity company (PLN), but some use their own power plant by using generator. Private power plants generally use diesel oil as fuel and the cost of energy consumption varies depending on the amount of fuel used. At first many industries in Indonesia use fuel diesel because the price is relatively cheaper than gasoline. But since the year 2009, the Indonesian government set the same price for gasoline and fuel diesel, so now the industry has begun to change their power plant by using gasoline.

Energy in natural rubber latex concentrate processing is used to operate equipments such as centrifuges, macerator, creper , hammer mill and drying machine. As for energy intensity, Factory A has greater energy intensity compared to Factory B both in concentrated latex processing and block skim rubber processing. Centrifuge is the equipment that uses the most energy in concentrated latex processing. In block skim rubber processing, dryer is the equipment that uses the most energy followed by hammer mill, and presses. Therefore more attention is required to use energy more efficiently. Factory A emits higher air emissions compared to Factory B, based on measurements of air emissions that have been set by the government namely SO_2, NO_2, and particulate. This is supported by the results on air emission as discussed in section 4.4.4. This indicates that factory B is more eco-efficient in term of energy use.

Relatively, energy use cause less impact on the environment compared to chemical, but based on section 4.5.2, energy consumption for both factories are still higher compare to similar industries. So reducing energy consumption should be pursued. Energy consumption for block skim rubber processing is 40% more compared to latex concentrate processing for Factory A.

Energy consumption for block skim rubber processing is higher by 34% compared to latex concentrate processing in Factory B. The two conditions above show that energy consumption in block skim rubber is still higher than latex concentrate processing, whereas the selling price of latex concentrate is U.S. $1.82 per kg of latex concentrate (MRB, 2012) and higher than the average price of block skim rubber at U.S. $1.4/ kg block skim rubber (Alibaba, 2012). As a result, reducing energy consumption for both commodities, especially block skim rubber processing should be done. Reducing energy consumption is one way to reduce the impact on the environment as well as one element of the 7 elements in eco-efficiency.

Reduction of energy consumption can be achieved in several ways:

- Start up of centrifuge takes 10-15 minutes to get rotation bowls in centrifuge at 6,000 rpm before the latex can be fed into the bowls. Friction between air inside the bowls, makes the bowls becomes hot and causes energy loss. Water is added bring down the temperature. Lots of energy loss in centrifuge occur during start up, given every 2-3 hours centrifuge must be stopped for cleaning.

  According to Jawjit et al. (2012), to reduce energy consumption during start up, installation of inverter to some centrifuge allowing distribution of electric current to machines until the desired rotation are met. This method can reduce energy consumption by 10-12%.

- Replace the old centrifuge (clutch and gear system) with a new machine by using variable pulley to adjust RPM (revolution per minute) of the centrifuge method can reduce energy consumption by 20% (DIW, 2001)

- Crumbs entering the dryer should have as little water content as possible, so that the energy required for phase change (latent heat) of water become less. Improved controll of rubber moisture and combustion conditions may reduced energy consumption by about 15% (DIW, 2001)

- Motor as a driver on the equipments such as centrifuge, macerator, creper, hammer, in natural rubber latex concentrate processing should be energy efficient. Motors, heaters system are the main electrical energy users in rubber processing and motors use approximately two-thirds of the energy costs in rubber processing (Technology, 2009).

- Centrifuge is a tool which uses energy the most in the process to separate concentrated latex; for block skim rubber processing, hammer mill is a device that uses energy more after the dryer. Based on energy audit by Saidur (2010), electric motor used more energy followed by heater and cooling system in rubber industry. Emission of CO_2, SO_2, NO_x and CO will be increased by increasing the speed power of motor but simultaneously will increase energy saving. Oversized motors are inefficient and equipment needs to be carefully matched. Saidur (2010) stated that saving energy could be done by regular maintenance of motorized equipments such as cutter. This activity has the potential to reduce energy by one third (W. Jawjit, et al., 2012). Furthermore, controlling rubber moisture and combustion will reduce energy consumption by 15%.

- Reducing water consumption will have an impact on reducing the volume of wastewater and also reduces energy consumption. Water in the factory is distributed by the pump using energy derived from the use of electricity.
- In order to reduce fossil fuel usage, Reno (2010) offer sugarcane bagasse as energy alternative which will produce biofuel with less impact to the environment to substitute fossil fuel.

4.7.2.3.Water Intensity

A great quantity of the water consumed in latex concentrate processing is used for cleaning equipment and surrounding processing area. For block skim rubber processing, water is used for washing solid rubber from skim latex and cup lumps from plantation known as bokar which has poor quality and cleaning surrounding area. Based on eco-efficiency calculation, water intensity for Factory A on latex concentrate processing is 1.7 times greater than Factory B, and 3 times higher on block skim rubber processing. Thereby Factory B is found to be more eco-efficient in water consumption.

Based on Table 4.20 water consumption varies greatly. The increase in processing capacity of latex concentrate and block skim rubber does not follow increase in water consumption. Water usage is not standardized and still is based on the habits and visual measurements. As a result, over-consumption of water use will affect eco-efficiency.

Block skim rubber processing uses more water than latex concentrate processing at Factory A and Factory B. So it will give low eco-efficiency or high water intensity. Water consumption is higher in block skim rubber, certainly will lower the eco-efficiency considering the price of block skim rubber is lower than latex concentrate.

Reducing water consumption can be done in several ways:

1. The excessive amount of acid in coagulum would require a large quantity of water to clean the coagulum
2. Cup lumps (bokar) from the plantation must be clean with no wood or sand that will require a large quantity of water to clean. Lumps should meet the requirement of SNI 06-2047-2002.
3. Utilize high pressure cleaning systems with pressures up to 500 kPa, to wash the floor in processing area in a short time and reducing water consumption . This system can reduce water consumption up to 60%.
4. Use waterless cleaning equipment with function as a sweeper and brushes for cleaning the equipments such as sedimentation tanks, centrifuge before rinsing with water. This technique can reduce water consumption and takes a short time to do, and minimize water to wastewater treatment.
5. To reprocess the water that has been used, and then reused. Basically the function of water in the latex concentrated separation process to clean the floor in factory area and most widely used for cleaning tools such as: skim gutter and centrifuge bowl. Meanwhile, the centrifuge bowl used more water than other equipments, because it should be washed every 2 hours to avoid clogging. Technologies that are used to treat wastewater for reuse can involve improvements of methods such as: precipitation and sedimentation, biological treatment, filtration through media or membranes, reverse osmosis. Reprocessing of wastewater in natural rubber latex concentrate processing can be done to reuse the water by separating rubber particles, or chemical compounds such as excess ammonia and excess acid. Therefore usage of fresh water is reduced. Reprocessing water is offered in a simple way as shown in Figure 4.31.

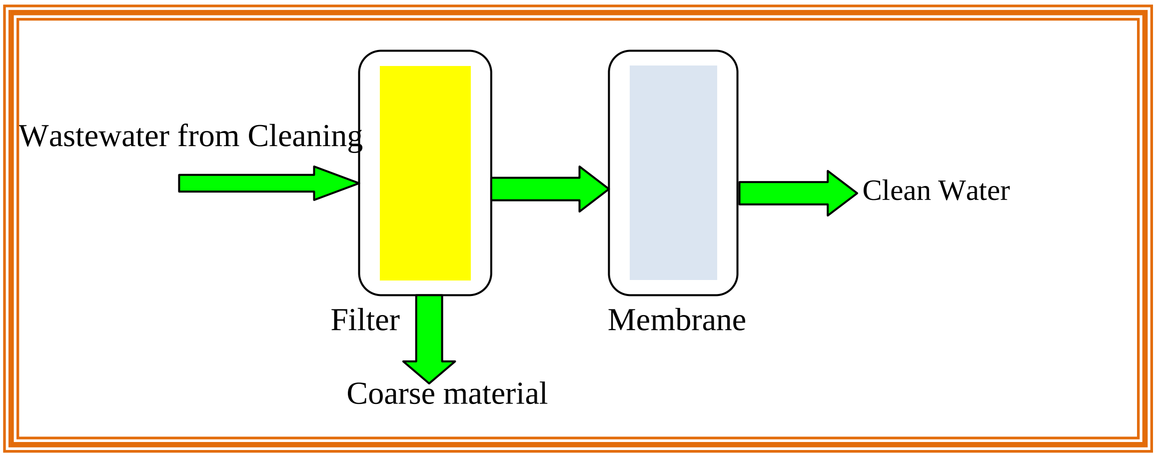


Figure 4.31: Reprocessing of wastewater

6. Companies can use rainwater harvesting because the rainfall in North Sumatra is quite high, especially in the months of August until February. The maximum rainfall is 313.1 mm rainfall in January and minimum of 63.2 mm in August (Dephut, 2002). Waste minimization can also reduce water consumption, because waste needs water for cleaning.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

The concentration of field latex is achieved through centrifugation, which is a mechanical separation process employing centrifugal force at 6500 rpm to produce a concentrated field latex layer and a skim rubber layer. For both factories DRC in field latex ranges between 29% to 32% and after centrifugation 88%-90% dry rubber content goes towards latex concentrate and of 9.22% dry rubber content goes towards coagulation pond to form block skim rubber. A by product skim rubber is obtained after coagulation. The overall DRC losses is 1%.

Natural rubber latex concentrate processing requires chemicals additives that may affect the health of workers or the community around the factory. Factory A uses more chemical than Factory B both in latex concentrate processing and block skim rubber processing. Energy is needed to drive the motors and pumps as well as for the drying process. Generally processing block skim rubber processing consumes energy more than latex concentrate processing. Factory A is less efficient than Factory B since it uses 30% more energy. As for block skim rubber Factory A uses 36% more energy than Factory B. Natural rubber latex concentrate processing also requires a lot of water which will result in wastewater which needs treatment. Factory A uses 70% more water than Factory B for concentrated latex processing, while for block skim rubber processing, Factory A uses water 2.18 times more compare to Factory B. Therefore, chemical, energy and water are three components required in natural rubber latex concentrate processing, but furthermore will give negative impact on the environment.

According to ADB (2008) increase in material consumption are related to increased in residuals as wastes or pollution. Materials need to be used efficiently, irrespective wether they are from renewable non-renewable sources. Higher rubber losses in natural rubber latex concentrate processing will contribute more load more on the wastewater system.

Impact on environment of the natural rubber latex concentrate processing is calculated using the Eco-Indicator 99 method. A similar trend of impact to the environment in latex concentrate processing was shown by both factories. Fossil fuel is very dominant in impact categories and has the highest percentage value followed by respiratory in-organics, climate change and ecotoxicity. Ammonia which is used as preservative during the process is a very important compound to avoid latex coagulation, but at the same time it is a volatile compound. Based on the impact categories as in section 4.6 ammonia is the chemical that contribute the most impact.

In block skim rubber processing, fossil fuel gives the highest impact, followed by respiratory in-organics, carcinogens and climate change, and plastic packaging.

Based on research conducted, Factory A contribute higher environmental impact than Factory B for latex concentrate processing and block skim rubber processing. Damage to resources is very high and is dominated by fossil fuel.

Ammonia gives the highest impact in latex concentrate processing (92.7%) for Factory A with total impact of 30.998 Pt and for Factory B is 98.8% with total impact of 22.675 Pt.

The highest impact in block skim rubber processing for Factory A is caused by formic acid at 46.5% and plastic at 40.5% with total impact of 5.483 Pt, while for Factory B is caused by plastic at 64.5%, sulfuric acid at 27.6% with total impact of 3.439 Pt.

Excess ammonia will result in sequential impact, where ammonia itself cause air emission and wastewater pollution. The acid consumption to coagulate skim latex becomes higher, because the acid will be used to neutralize the excess ammonia. Higher acid consumption will cause difficulty for the rubber in skim latex to coagulate and as a result amount of suspended solid becomes high. Therefore ammonia must be in a minimum level before entering the coagulation pond to avoid acid excess.

For eco-efficiency measurement, 8 impact categories were chosen from 11 impact categories as the most influential impacts which cause environmental damage from latex concentrate processing and block skim rubber processing. It appears that damage to resource provides the smallest eco-efficiency in natural rubber latex concentrate processing for both factories followed by human health. Therefore there is a need to manage the resource and human health in order to improve the eco-efficiency.

Eco-Efficiency Indicator is determined by three factors: waste intensity, energy intensity and water intensity. Waste intensity influences the amount of wastewater parameters, such as BOD_5, COD, TSS, Total-N and NH_3N (ammonia total).Waste intensity is almost the same for both factories.

Based on eco-efficiency indicator, water intensity for Factory A for latex concentrate processing and block skim rubber processing is greater than Factory B. Therefore factory B is found to be more eco-efficient in water consumption.

As for energy intensity, Factory A has greater energy intensity compared to Factory B both for latex concentrate processing and block skim rubber processing. Factory A give greater emissions compared to Factory B. This indicates that factory B is more eco-efficient in energy consumption.

5.2 Recommendations

In this study, some suggestions are proposed to increase the eco-efficiency in natural rubber latex concentrate processing:

1. Proper usage of ammonia should be investigated so that the amount used is not excessive, and in accordance with its function as a preservative and it should not affect on the coagulation process.
2. Proper usage of acid as coagulant use during skim latex coagulation should be investigated, so that loading on the wastewater treatment should be reduced if not eliminated due to acid content in the effluent. Consideration should be given to the process that does not use acid as coagulant for the coagulation process.
3. There is a need to calculate impacts to environment arising from usage of equipment elaborate more such as centrifuge, sedimentation tank, mixer, storage tank and any other equipment.
4. Impact to environment of some chemicals such as lauric acid, ammonium laurate and tetramethylthiuram disulphide in this study is unknown. This material should be entered into a data inventory in latex concentrate processing.
5. This study only covers the processes in the plant. Further study studies need to include transport from plantation to the factory and from factory to consumer.

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APPENDIX A

Publication by Author

1. 2nd International Conference on Environmental Research and Technology (ICERT). , 2-4 June, 2010, Penang, Malaysia, *Impacts of Climate Change on Natural Resources: Case in Latex Concentrate Processing.*
   Seri Maulina[1]*, Nik Meriam Nik Sulaiman[1], Noor Zalina Mahmood[2]

2. 4th Environmental Physics Conference, Hurgada, Egypt, *Eco-Efficiency Analysis: Creating more values with less impact in latex concentrate processing,* 10-14 March 2010, Hurgada, Egypt.
   Seri Maulina[1]*, Nik Meriam Nik Sulaiman[1], Noor Zalina Mahmood[2]

3. Sriwijaya International Seminar on Energy Science and Technology 2009, *Eco-efficiency indicators in latex concentrate processing: energy intensity*, Universitas Sriwijaya Kampus Bukit Besar Palembang. UNSRI, Indonesia, 14 – 15 Oktober 2009.
   Seri Maulina

4. Chemeca 2009 Conference, Burswood Entertainment Complex, Perth, Australia, *Life Cycle Assessment and Eco-Efficiency: case in latex concentrate processing,* 27-30 September 2009
   Seri Maulina[1]*, Nik Meriam Nik Sulaiman[1], Noor Zalina[2]

5. The 8th International Conference on Eco Balance, Tokyo, Life Cycle Impact Assessment of different usage of Latex Concentrate Processing: Rubber Thread, Rubber Export, Rubber Glove, 9-12 December 2008,
   Seri Maulina[1]*, Nik Meriam Nik Sulaiman[1], Noor Zalina[2]

6. 15th Regional Symposium on Chemical Engineering (RSCE) in conjunction with the 22nd Symposium of Malaysian Chemical Engineers (SOMCHE)**,** *Comparison life cycle impact assessment of block skim rubber production by using different coagulant*, 2-3 December 2008, Kuala Lumpur

7. International Symposium on Environmental Management: Hazardous-Environmental Management Toward Sustainability, *Life cycle impact assessment of block skim rubber from natural rubber,* 22-23 September 2008, Royal Hill Resort & Spa Nakorn Nayok , Thailand.
   Seri Maulina[1]*, Nik Meriam Nik Sulaiman[1], Noor Zalina[2]

8. Third Regional Symposium on Environment and Natural Resources (RSENR3): Life Cycle Impact Assessment of Latex Concentrate from Natural Rubber, 5-6 Agust 2008, Kuala Lumpur.

9. Submission writing to International Journal of Engineering Research and Technology. Title: Overview source of impact to environment in natural rubber latex concentrate processing using LCA as a tool.

APPENDIX B

Calculation of Rubber Balance

1. Factory A

Weight of Field Latex = (1,000/541,860.30) * 2,116.504 kg = 3,906 kg
Rubber in Field Latex = (1,000/541,860.30) * 614,611.33 kg = 1,134 kg
Rubber in Concentrated Latex = 1,000 kg
Rubber in Skim Latex =(1,000/541,860.30) * 42.082 kg = 78 kg
Rubber losses = (1,000/541,860.30) * 6,084.33 = 11 kg
Rubber in Secondary Pond = (1,000/541,860.30) * 25,584.33 = 45 kg

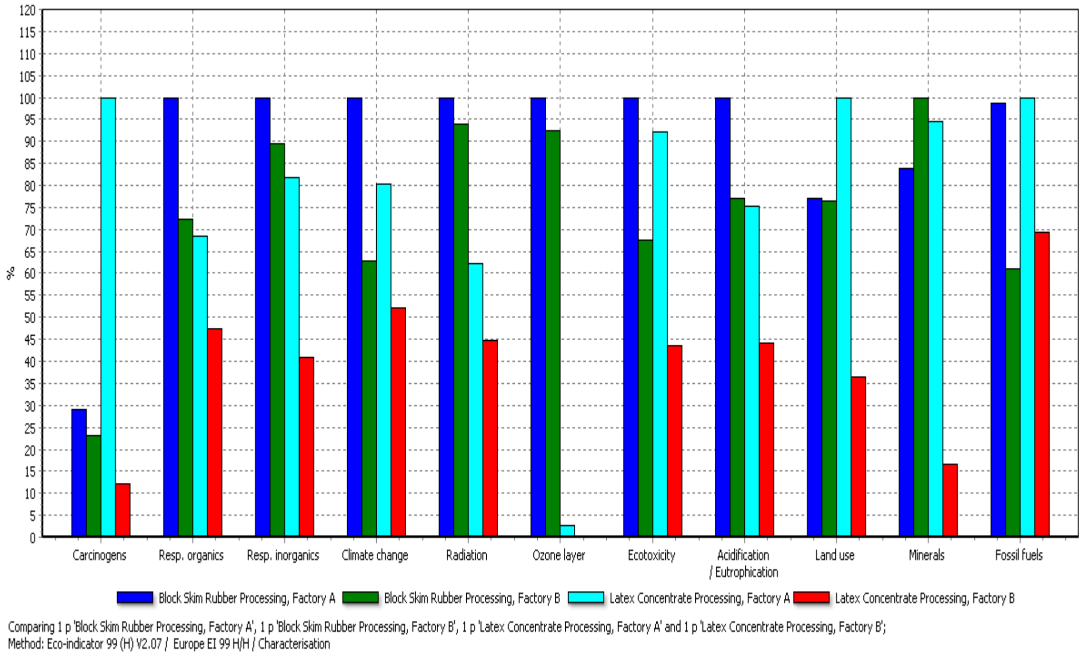
2. Factory B

Weight of Field Latex = (1,000/817,319) * 2,842.422 kg = 3,501 kg
Rubber in Field Latex = (1,000/817,319) * 910.004 kg = 1,113 kg
Rubber in Concentrated Latex = 1,000 kg
Rubber in Skim Latex =(1,000/817,319) * 62.546 kg = 75 kg
Rubber losses = (1,000/817,319) * 7,980 = 11 kg
Rubber in Secondary Pond = (1,000/817,319) * 22,159 = 27 kg

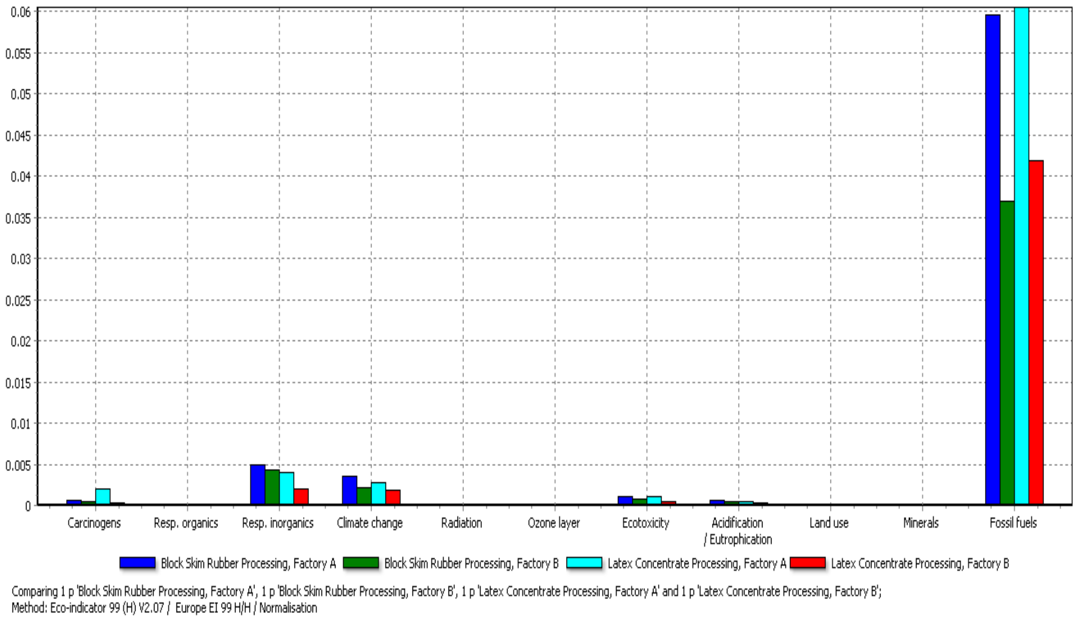
APPENDIX C

1. Sample of the output from Simapro in Natural Rubber Latex Concentrate Processing per Impact Category

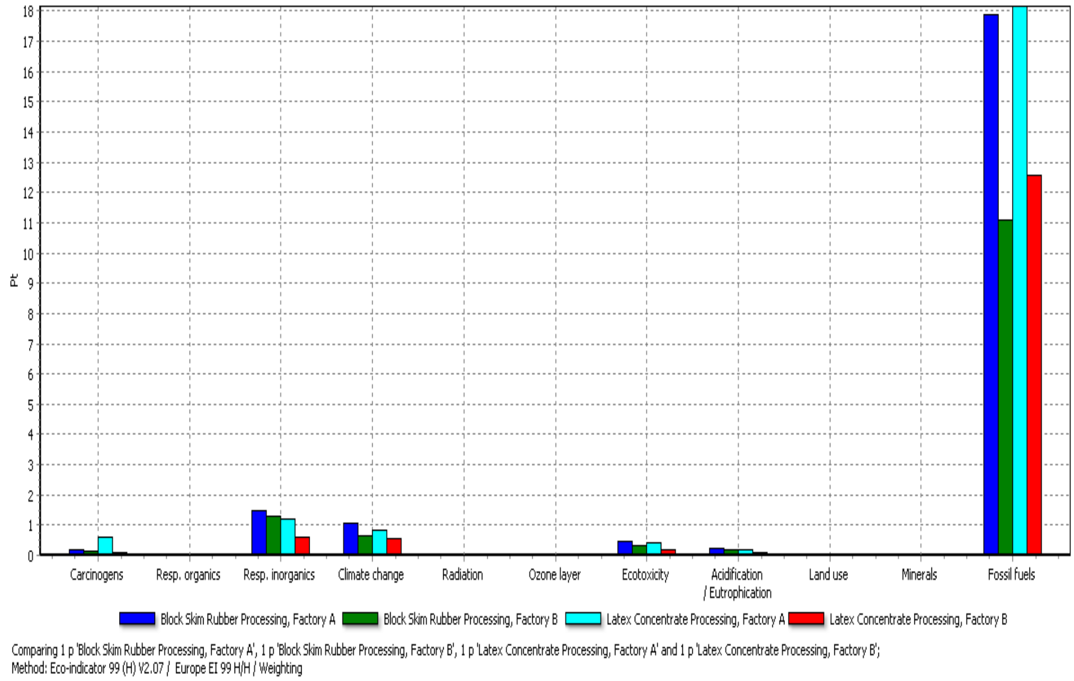
a. Characterisation



b. **Normalisation**

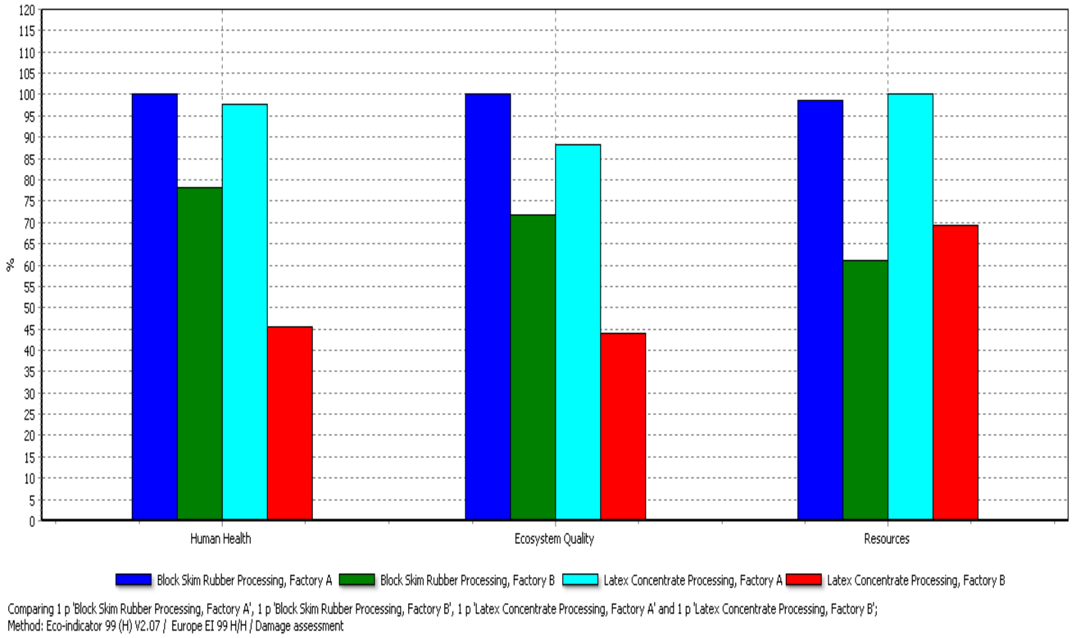


c. **Weighting**

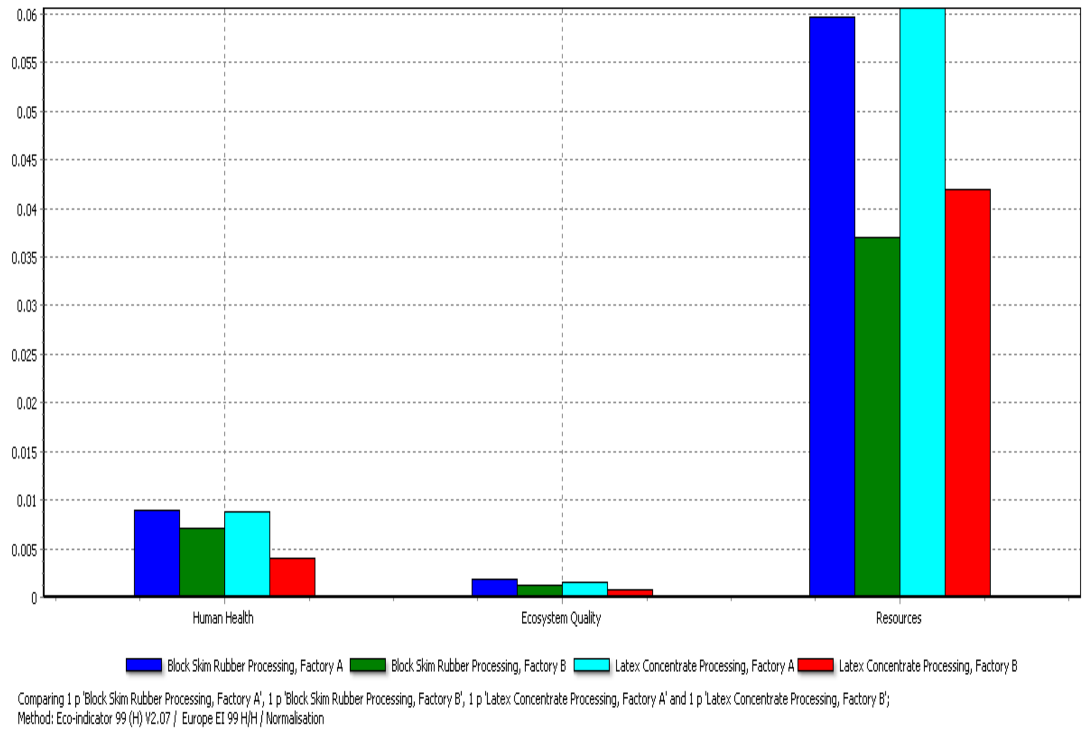


2. Sample of the output from Simapro in Natural Rubber Latex Concentrate Processing base on damage

a. Damage Assessment



b. Normalisation of Damage Assessment



c. Weighting of Damage Assessment